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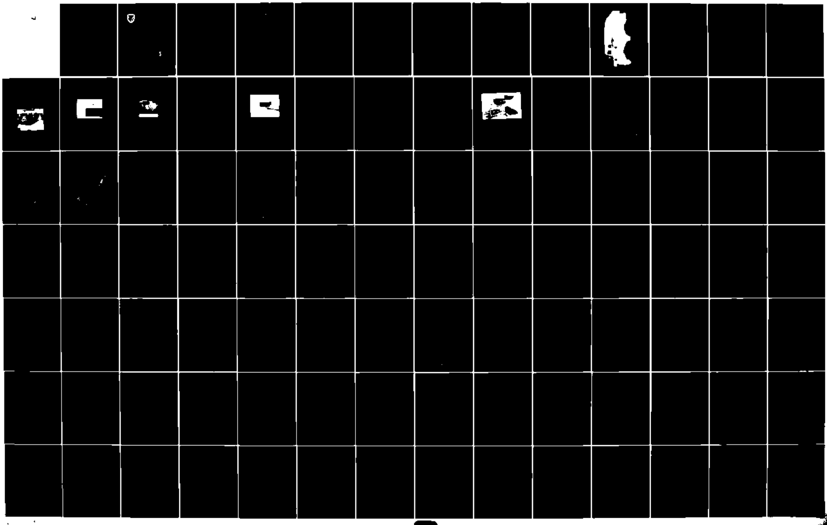

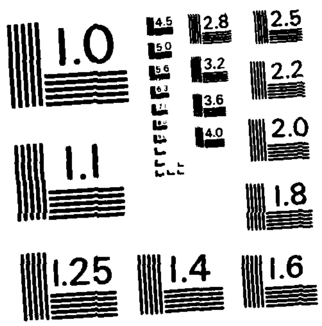

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RDI TASK FINAL REPORT

OF

VEHICLE PERFORMANCE RECORDER (VPR)/

HMMWV INTERFACE VERIFICATION

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The High Mobility Multi-Purpose Wheeled Vehicle is scheduled to undergo Initial Production Testing starting July 1984. It has been proposed that the Vehicle Performance Recorder be used during the endurance portions of this test to provide monitoring of the vehicle inputs. This report describes the instrumentation used and testing accomplished in the time frame of 26 March through 6 April 1984 to validate the Vehicle Performance Recorder/High Mobility Multi-Purpose Wheeled Vehicle interface and to determine a suitable indication of the power train loading. Among the conclusions reached is that the Vehicle

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20. Performance Recorder can be used for the indicated purpose, and the recommendation is made that it be used during the endurance portion of the Initial Production Test of the High Mobility Multi-Purpose Wheeled Vehicle.

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ABSTRACT

The High Mobility Multi-Purpose Wheeled Vehicle is scheduled to undergo Initial Production Testing starting in July 1984. It has been proposed that the Vehicle Performance Recorder be used during the endurance portions of this test to provide monitoring of the vehicle inputs. This report describes the instrumentation used and testing accomplished in the time frame of 26 March through 6 April 1984 to validate the Vehicle Performance Recorder/High Mobility Multi-Purpose Wheeled Vehicle interface and to determine a suitable indication of power train loading. Among the conclusions reached is that the Vehicle Performance Recorder can be used for the indicated purpose, and the recommendation is made that it be used during the endurance portion of the Initial Production Test of the High Mobility Multi-Purpose Wheeled Vehicle.

FOREWORD

The Materiel Testing Directorate (MTD) of Aberdeen Proving Ground (APG) MD, was responsible for the design of the Vehicle Performance Recorder (VPR) and its software, and for the testing described in this report. Mr. Lloyd Foss, Jr. of MTD was responsible for the software used in the reduction of VPR data. Mr. Doug Woolcott and Mr. Dwayne Hood of AM General contributed to the overall success of this effort.

SECTION I. BODY

1. BACKGROUND

In the time frame 1976 through 1980 an ongoing project, Automated Data Acquisition and Processing Techniques (ADAPT), resulted in a state-of-the-art system for the test and evaluation of Army materiel (app J, ref 1). In the case of vehicles, this system relies heavily on a sophisticated telemetry system to acquire data.

During the development of the Data Acquisition and Processing System it was generally recognized that the telemetry system was targeted at road-shock and vibration and engineering/performance testing, and would not be widely applicable to a large body of vehicle testing, including endurance testing. A follow-on effort (MICRO ADAPT) was therefore initiated. The objective of this effort was the development of small, highly ruggedized data acquisition and processing systems which could be mounted on test vehicles to acquire and process data (largely unattended) for later retrieval and further analysis in a general purpose computer. This project is at a stage where it is possible to apply some of the technology that has been developed.

Concurrent with these developments the Army initiated the development and procurement of the High Mobility Multipurpose Wheeled Vehicle (HMMWV), shown in Figure 1-1. During earlier endurance testing of the HMMWV at different agencies, apparent discrepancies relative to the vehicle's endurance surfaced. This situation led to the mandate that instrumentation be used during the endurance portion of the HMMWV Initial Production Test (IPT) to provide a quantification of test severity. Two approaches to HMMWV endurance test instrumentation were developed. The first, proposed by the vehicle manufacturer, was the use of a vertical accelerometer mounted on the right rear gear hub with maximum values above a preset threshold recorded by a bump recorder (app G). The second proposed method involves use of the Vehicle Performance Recorder (VPR). A HMMWV was made available to MTD from 26 March through 6 April 1984 to allow verification of the VPR concept and to evaluate the vehicle/instrumentation interface.

1 (Cont'd)

Figure 1-1. High Mobility Multipurpose Wheeled Vehicle (HMMWV).

2. OBJECTIVES

The objectives of this report are to:

a. Determine the feasibility of using the Vehicle Performance Recorder (VPR) during IPT of HMMWV.

b. Evaluate the HMMWV transducer mounting techniques.

c. Evaluate the appropriateness of the parameters being measured.

3. DETAILS OF TASK

3.1 HMMWV - VPR Integration Tests

3.1.1 Parameters Measured

The instrumentation requirement for the IPT of HMMWV is for a system to quantify the severity to which the test items are subjected. (Note that severity as used here is not a well defined term from a scientific point of view.) The parameters which were monitored during this investigation were:

a. Right rear control arm position.

b. Right rear control arm acceleration.

c. Transmission fluid temperature.

d. Engine RPM.

e. Road speed.

Additional parameters have been proposed for the HMMWV IPT but were not included in this test.

a. Number of times brakes applied.

b. Accumulated duration of brake applications.

c. Gear (ratio of engine speed to road speed).

The first two items, control arm position and acceleration, were chosen as a measure of severity from the suspension point of view. The position is a measure of the extension and compression of the suspension, while the acceleration yields a measure of the forces involved. Figure 3-1 shows the relative position of these tranducers. Also shown in this figure is the placement of the accelerometer used with the bump recorder.

3.1.1 (Cont'd)

The transmission fluid temperature is an indicator of required torque. Appendix F should be consulted for the rationale for using this parameter.

The remainder of the parameters listed are indicators of operator inputs to the vehicle, and are included to allow variations from operator to operator to be accounted for.

3.1.1 (Cont'd)

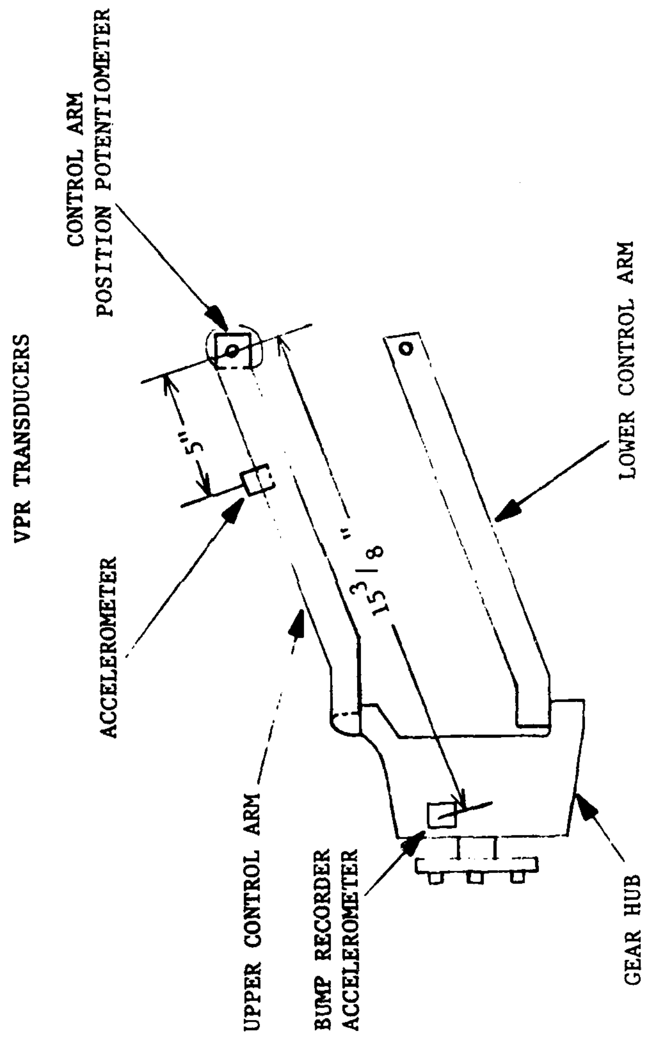


Figure 3-1. Control arm position and acceleration transducer placement.

3.1.1 (Cont'd)

The transducers used in the various measurements are listed in Table 3-1.

TABLE 3-1. TRANSDUCERS

Parameter	Transducers
Control arm position	Potentiometer, Maurey Model 112-P16-102
Control arm acceleration	Accelerometer, Statham Model 2262C-25
Transmission fluid temperature	RTD, Omega Model KE2528
Engine RPM	STE-ICE (internal)
Road speed	Optical Speed Sensor, Mass Tech Model TR 18A-1111-60

The potentiometer and accelerometer used to measure control arm position and acceleration respectively are shown in Figure 3-2. These transducers were mounted on the right rear upper control arm, a location that provided the maximum protection attainable.

Figure 3-2. Control arm position and acceleration transducers.

3.1.1 (Cont'd)

The remaining transducers were mounted in locations such that photographs were not possible. The transmission fluid temperature transducer was installed in the tubing between the transmission and the transmission fluid cooler. The road speed transducer was installed between the transfer housing and the speedometer cable assembly. Figures 3-3 and 3-4 are photographs of these two transducers. The engine rpm was measured using the existing Simplified Test Equipment-Internal Combustion Engine (STE-ICE) transducer (internal to the engine).

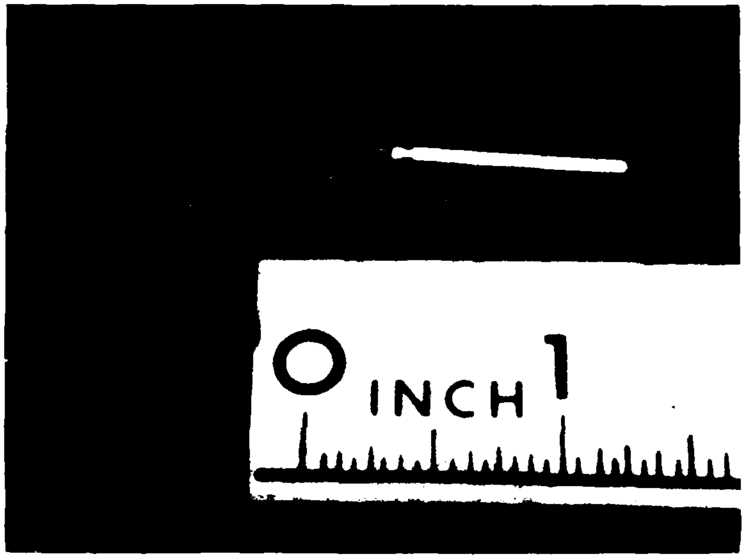


Figure 3-3. Transmission fluid temperature transducer.

3.1.1 (Cont'd)

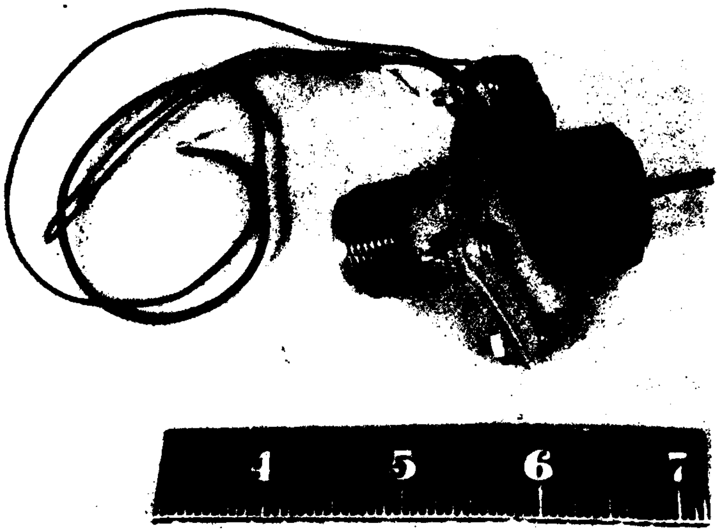


Figure 3-4. Road speed transducer.

3.1.2 Instrumentation

3.1.2.1 Vehicle performance recorder (VPR). The VPR, shown in Figure 3-5, is a small, self-contained data acquisition and processing system. It is designed to be installed on a vehicle to acquire and process data and store the results to provide a description of either system performance or test environment, or both.

Figure 3-6 is a block diagram of the VPR. The system is composed of nine printed circuit assemblies (six commercially available, three developed in-house) and a microterminal for operator interface. These printed circuit assemblies provide the following:

a. An 8 bit CMOS microcomputer (with 4 K bytes programmable readable only memory (PROM) and 2 K bytes random access memory (RAM)).

b. Terminal interface.

c. Sixteen K bytes of additional PROM program storage.

d. Thirty-two K bytes of additional RAM memory.

e. Thirty-two channel analog to digital converter.

f. Four channel counter/timer.

g. Four channel pulse conditioners.

h. Four channel analog signal conditioner.

Data from these channels may be processed and stored. The major limitations on the VPR's capabilities is the 32 K byte of RAM which is used to store either processed or raw data, and the speed with which the system's 8 bit microprocessor can process the data required.

The VPR will accommodate the following data channels:

a. Four analog (non-thermocouple).

b. Sixteen thermocouple (requires a thermocouple preprocessor).

c. Eight discrete event (on/off).

d. Four pulse or counter/timer.

3.1.2.1 (cont'd)

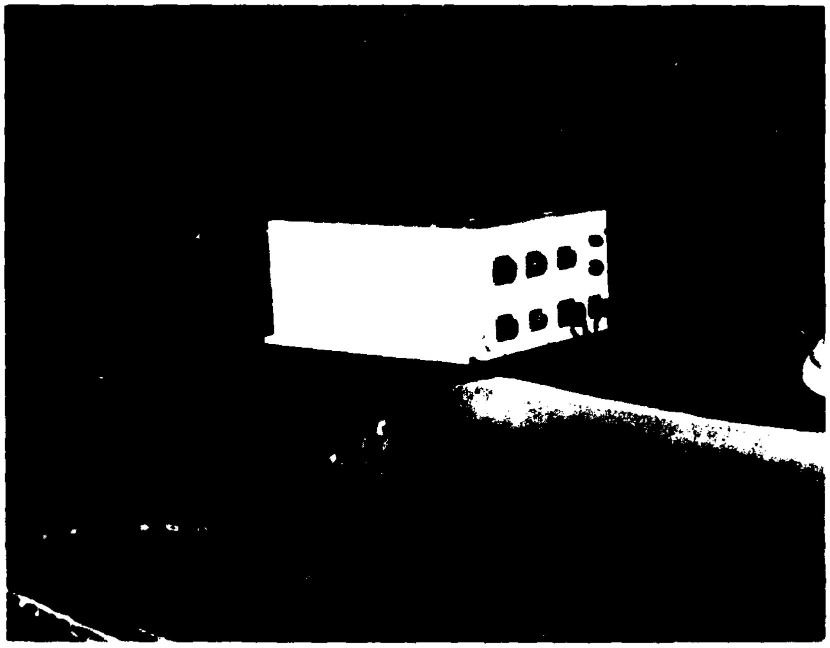


Figure 3-5. Vehicle performance recorder.

A major element of the VPR which does not appear in Figure 3-6 is the VPR software. This software, written in assembly language and Pascal on a host development system, is PROM resident. The commercially available embedded computer operating system kernel VRTX (Versatile Real Time Executive) and extensions supply the operating system environment. The software is designed in terms of system primitives which are easily interfaced to applications software.

Because of the VPR's limited data memory, some form of real time data reduction must be performed. Data reduction is the process of condensing a quantity of data until only the important properties remain, or, in some cases, operating on the data such that the important properties are emphasized. Included in the VPR software are a histogram task (app A and app J, ref 2 and 3) and a tachograph task (app E). The nature of these processing algorithms is such that the maximum information can be packed into the available storage. The structured nature of the VPR software is designed, however, so that other processing tasks can be easily added.

3.1.2.1 (Cont'd)

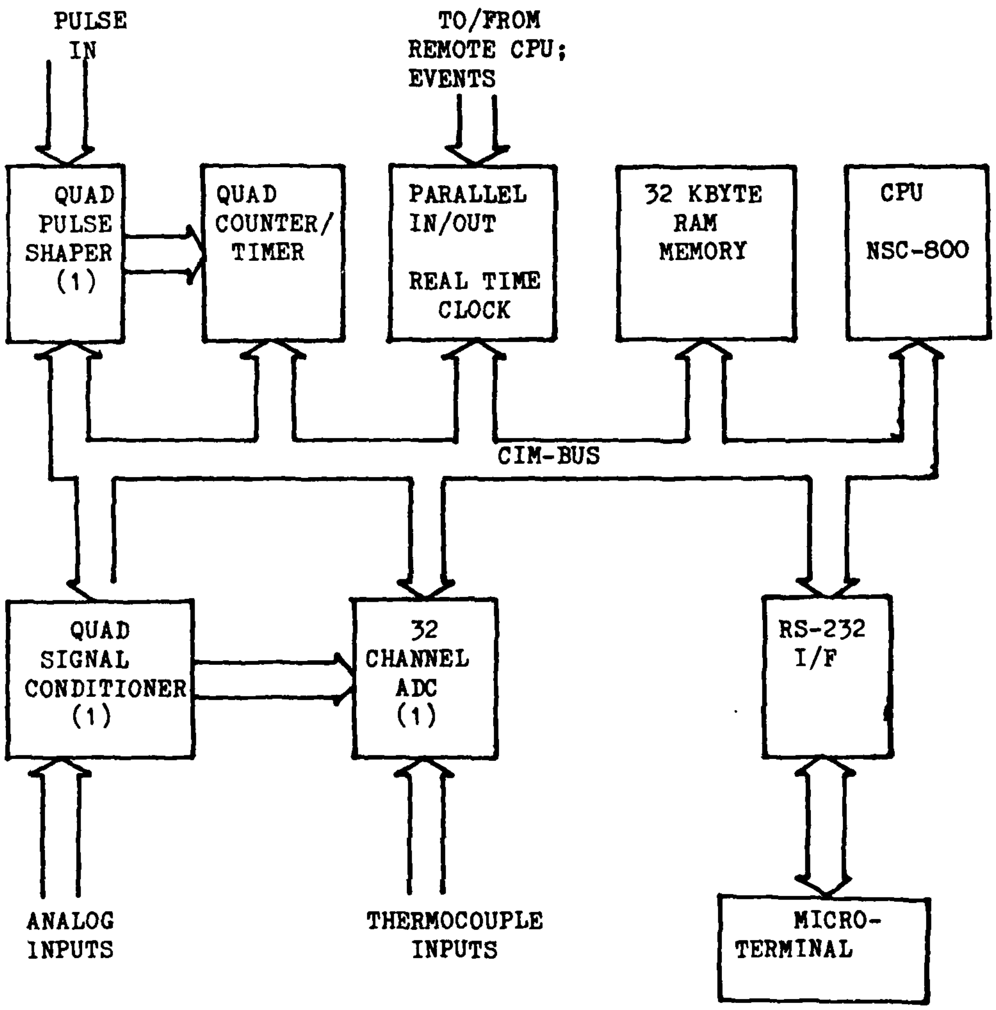


Figure 3-6. Vehicle performance recorder block diagram.

3.1.2.2 Telemetry Data Acquisition System. The basic APG telemetry data acquisition system is described in detail in Appendix J, Reference 1. A block diagram of this system as it was configured for use during the VPR/HMMWV integration verification is shown in Figure 3-7.

During this test, the transducer interfacing and signal conditioning were carried out in the VPR. A special cable harness was installed in the VPR to allow signals to be routed to the mobility signal conditioning unit. The data were then digitized, encoded into a serial pulse code modulated (PCM) signal, and transmitted from the vehicle. The data were sampled at a rate of 96.481 samples per second per channel, which was about twice the basic sampling rate of the VPR. Figure 3-8 is a photograph of the instrumentation installed on the HMMWV.

In the telemetry ground station the serial stream was received, and the digital data extracted. This data was input to a computer system, where it was stored (using disc storage) for a variety of later data processing.

Comparison data were acquired while the vehicle traversed the 6 inch washboard course (approximately 2 minutes duration), a combination of the gravel and Belgian block courses (approximately 15 minutes duration) and the Perryman cross country 3 course (approximately 15 minutes duration).

3.1.2.2 (Cont'd)

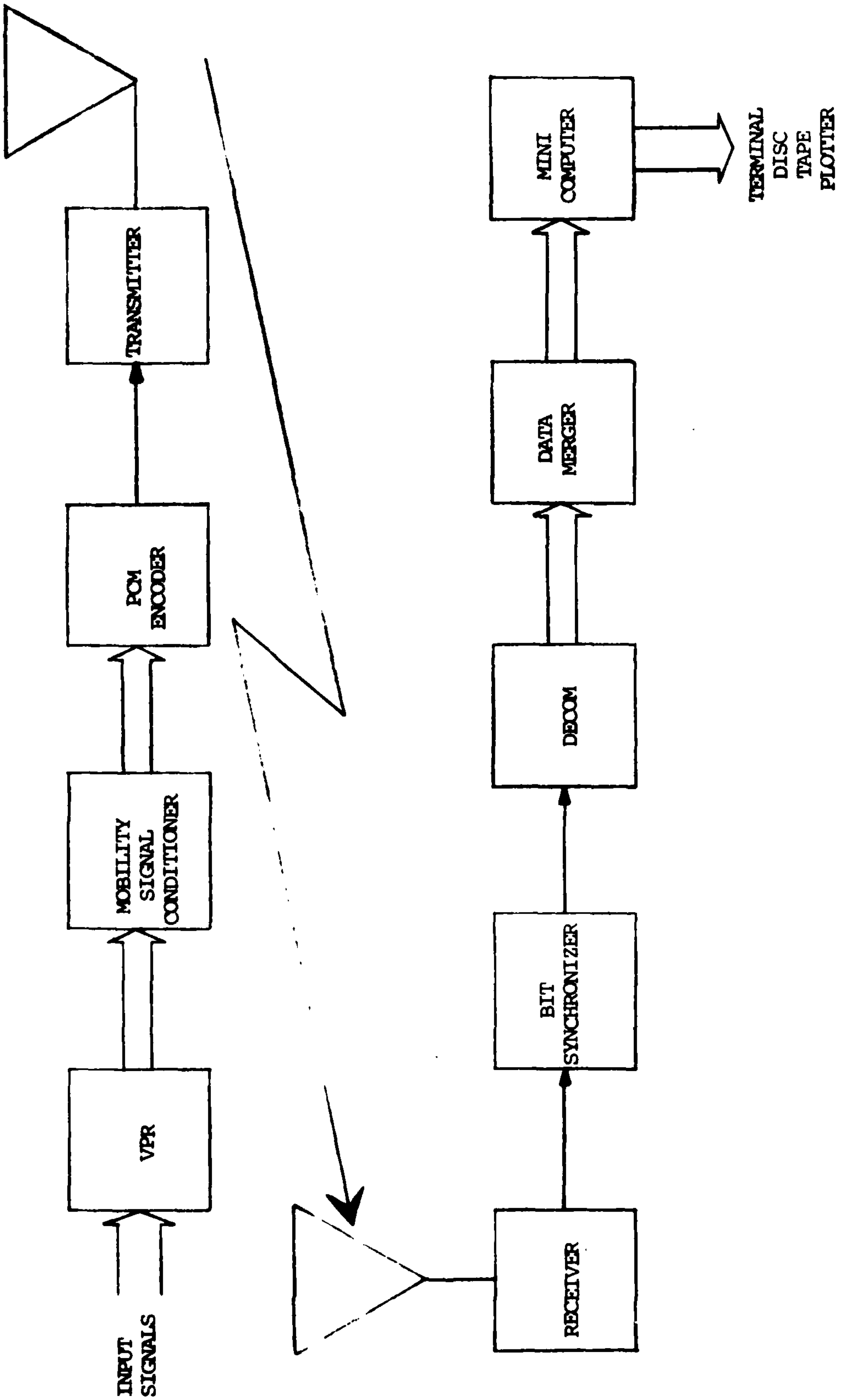


Figure 3-7. PCM telemetry system.

3.1.2.2 (Cont'd)

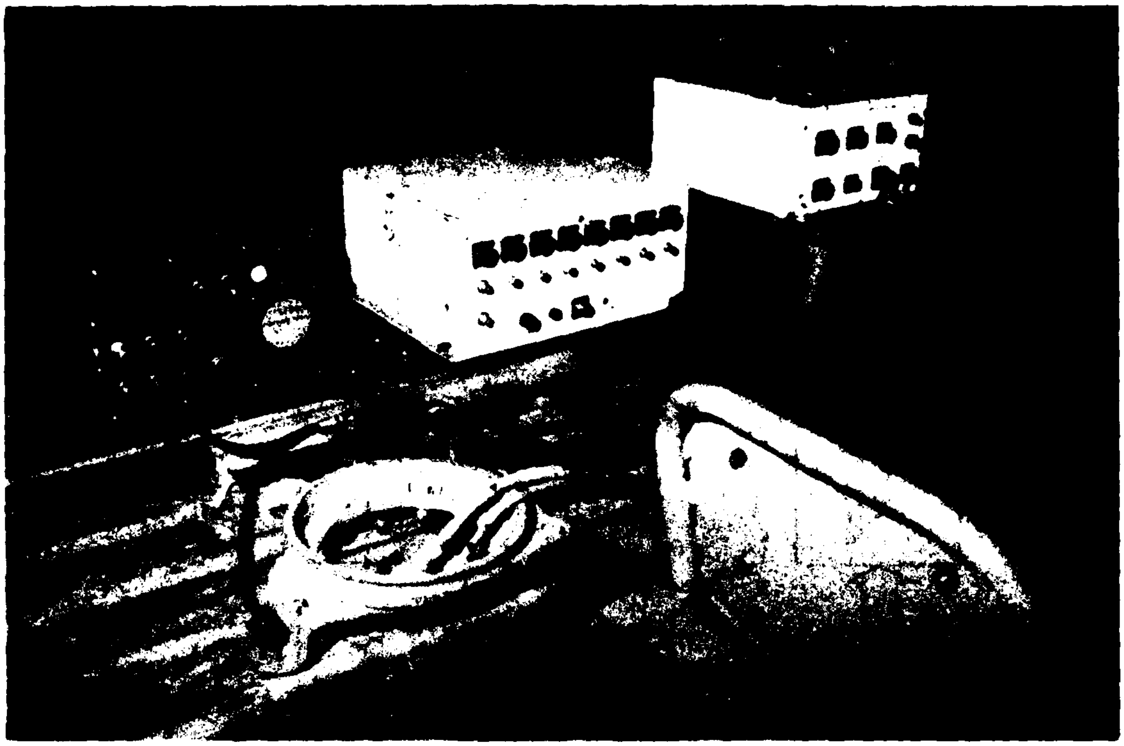


Figure 3-8. Instrumentation.

3.1.3 Results

The PCM acquired time history data were scaled in engineering units. Representative plots of this data are presented in Figures 3-9 through 3-12. Representative power spectral density (PSD) plots are presented in Figures 3-13 and 3-14.

Histograms, using the same bin limits as used in the VPR, of the scaled time history data were generated, and plotted on a digital plotter. The histograms developed by the VPR were transferred to the data acquisition computer, and these were also plotted. For purposes of clarity, 100 was added to the run numbers to identify data acquired using the telemetry system, i.e., runs 7 and 107 contain data acquired at the same time using the VPR and PCM systems respectively. Representative plots of these histograms are shown in Figures 3-15 through 3-18. All the VPR generated histograms are presented in Appendix B, and all those derived from the time history data are in Appendix C. Table 3-2 is an index to the comparison data. Note that there are several sets of VPR histograms with no corresponding time history derived histograms.

Data from the control arm position transducer acquired at Perryman cross country 3 (runs 113 and 13) are not presented because of a slippage problem in the transducer linkage. The engine speed data are not presented because these data were eliminated during a VPR program change which occurred just prior to these runs.

3.1.3 (Cont'd)

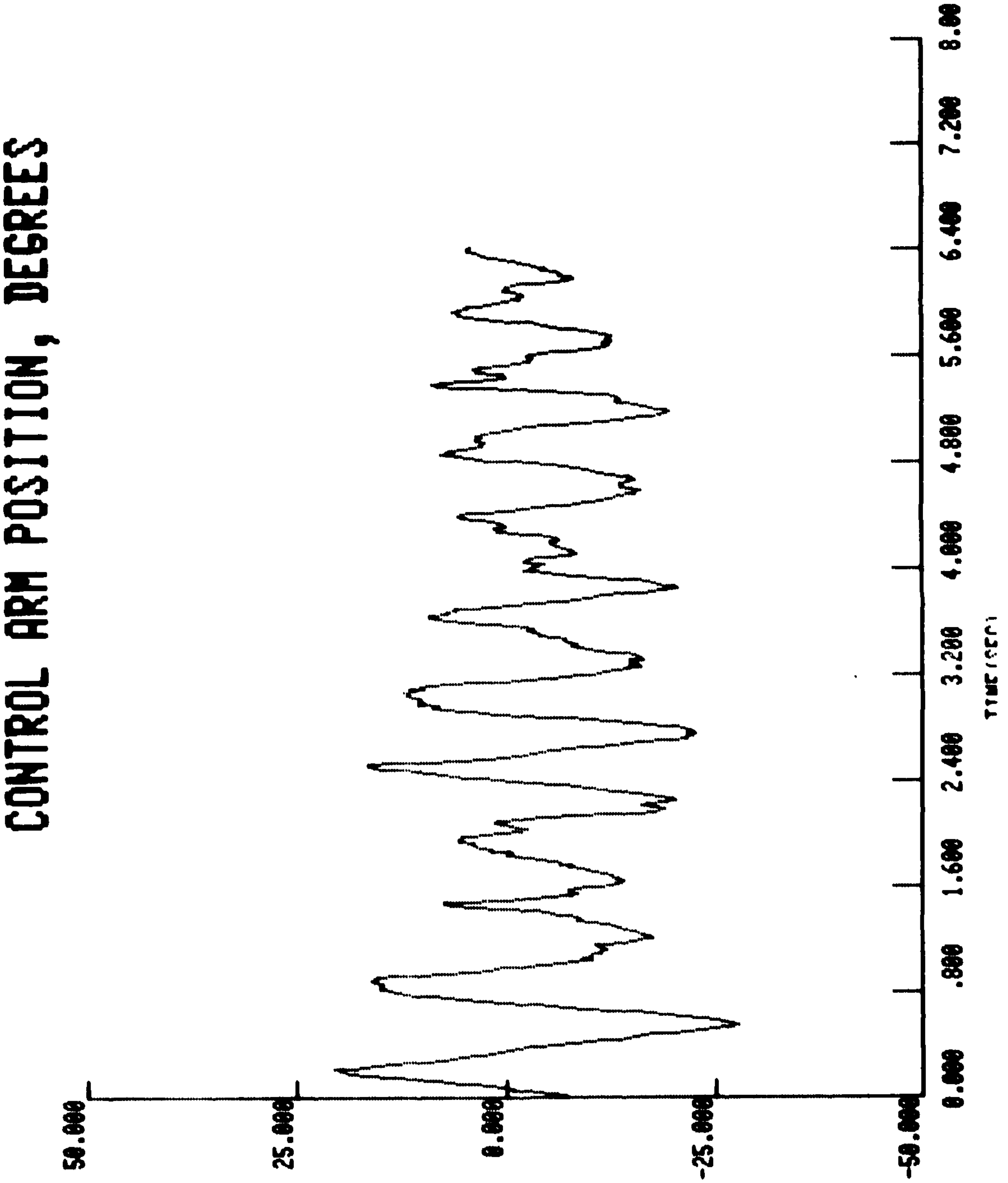


Figure 3-9. Control arm position time history.

3.1.3 (Cont'd)

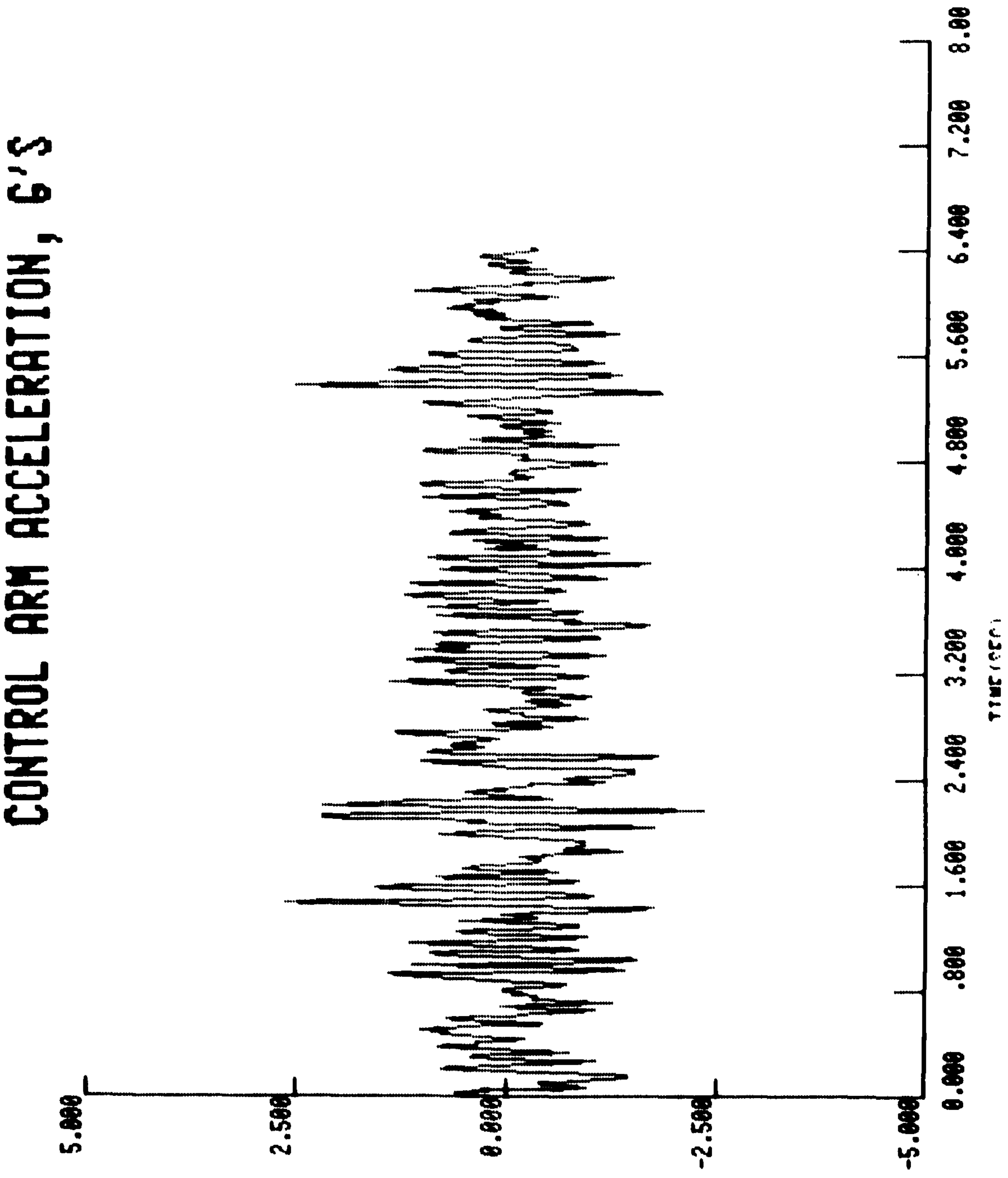


Figure 3-10. Control arm acceleration time history.

3.1.3 (Cont'd)

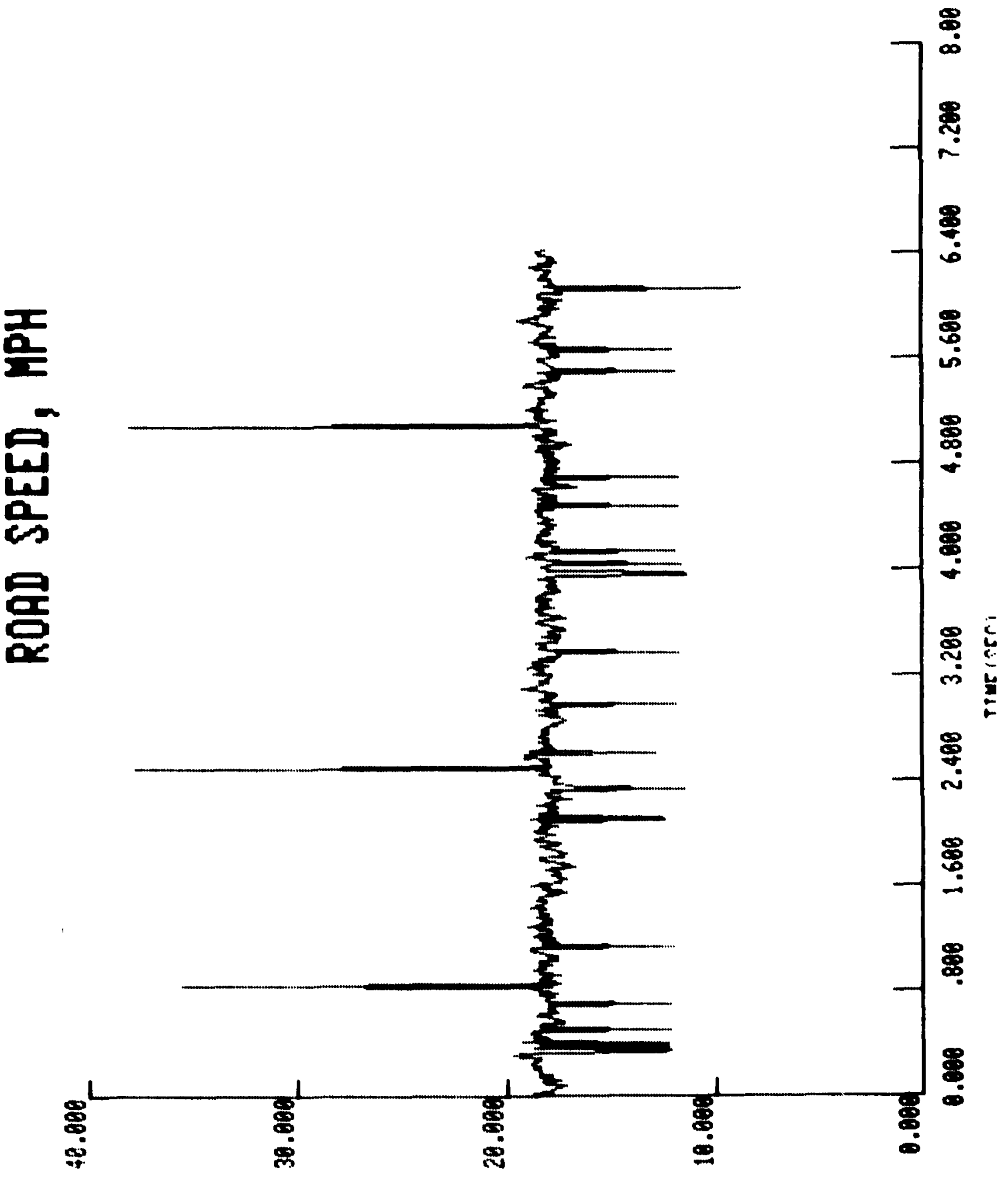


Figure 3-11. Road speed time history.

3.1.3 (Cont'd)

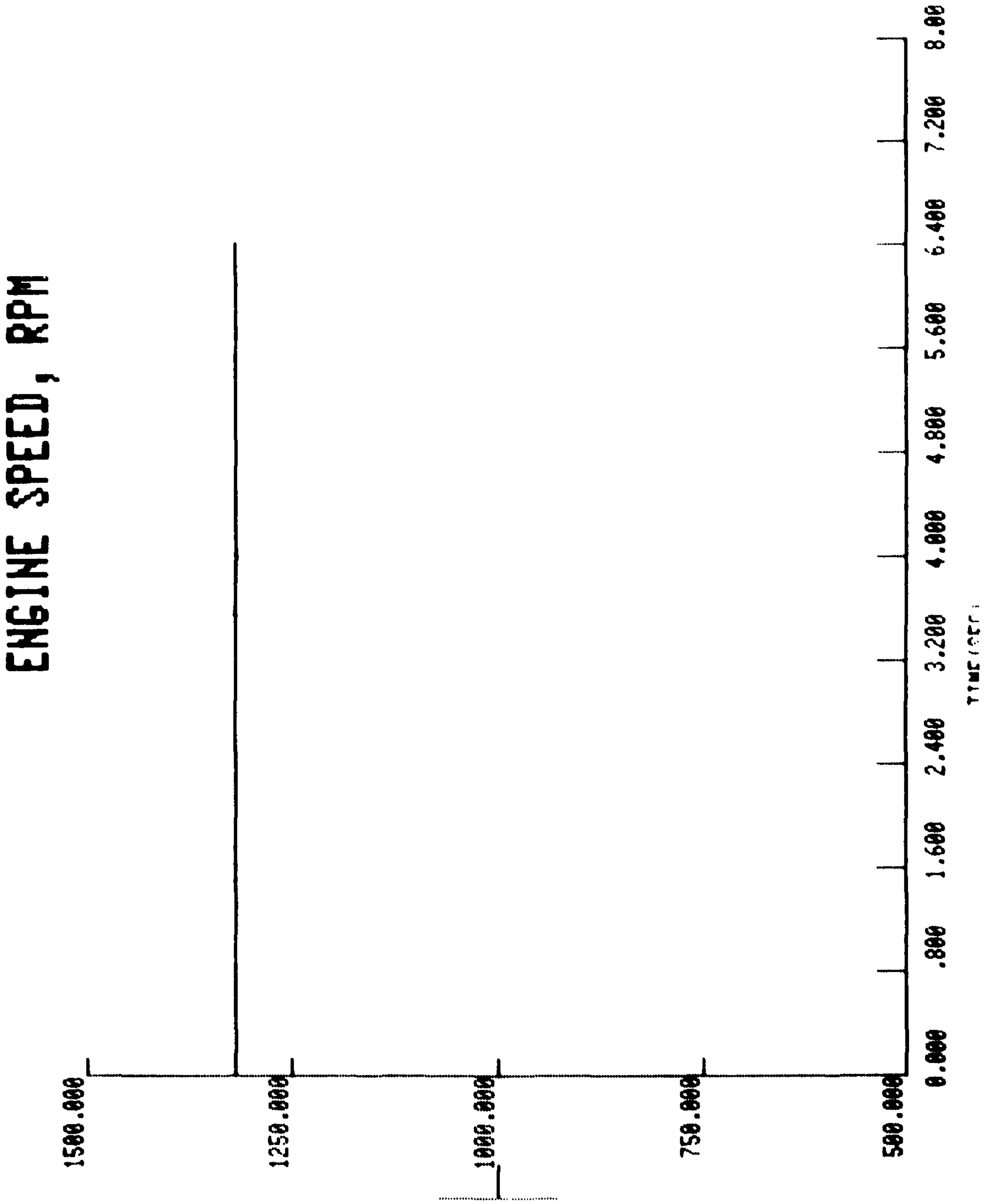


Figure 3-12. Engine speed time history.

3.1.3 (Cont'd)

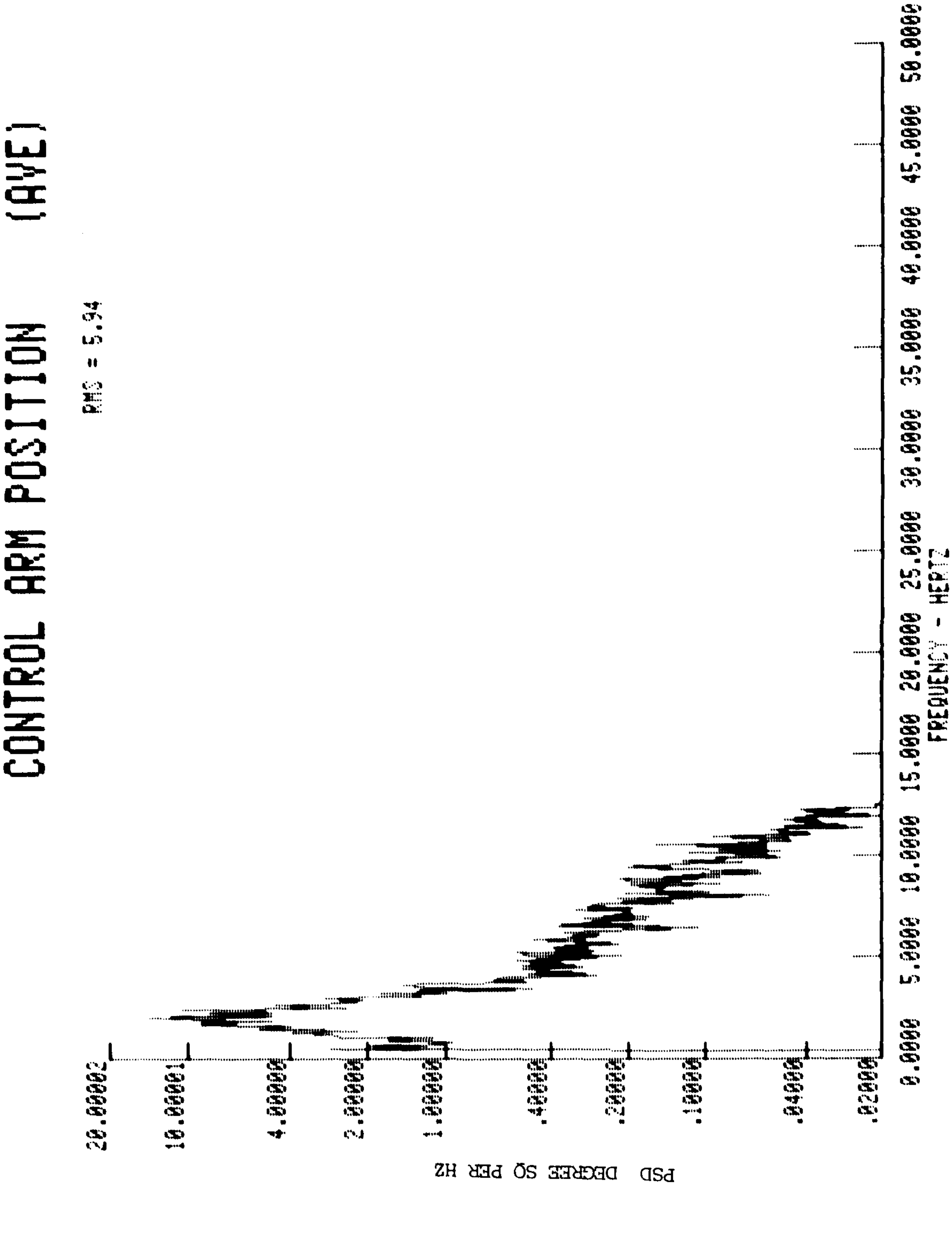


Figure 3-13. Control arm position PSD.

3.1.3 (Cont'd)

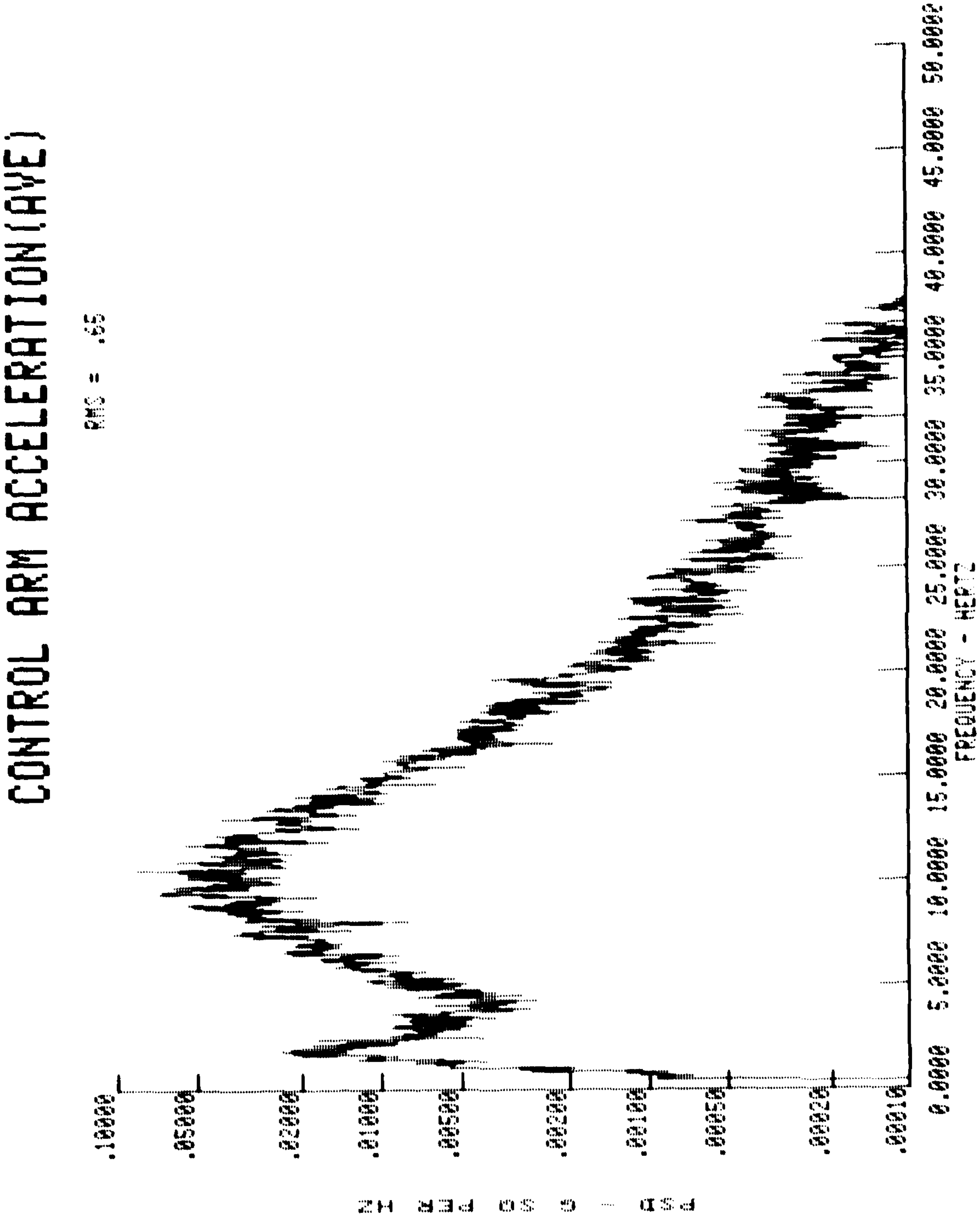


Figure 3-14. Control arm acceleration PSD.

3.1.3 (Cont'd)

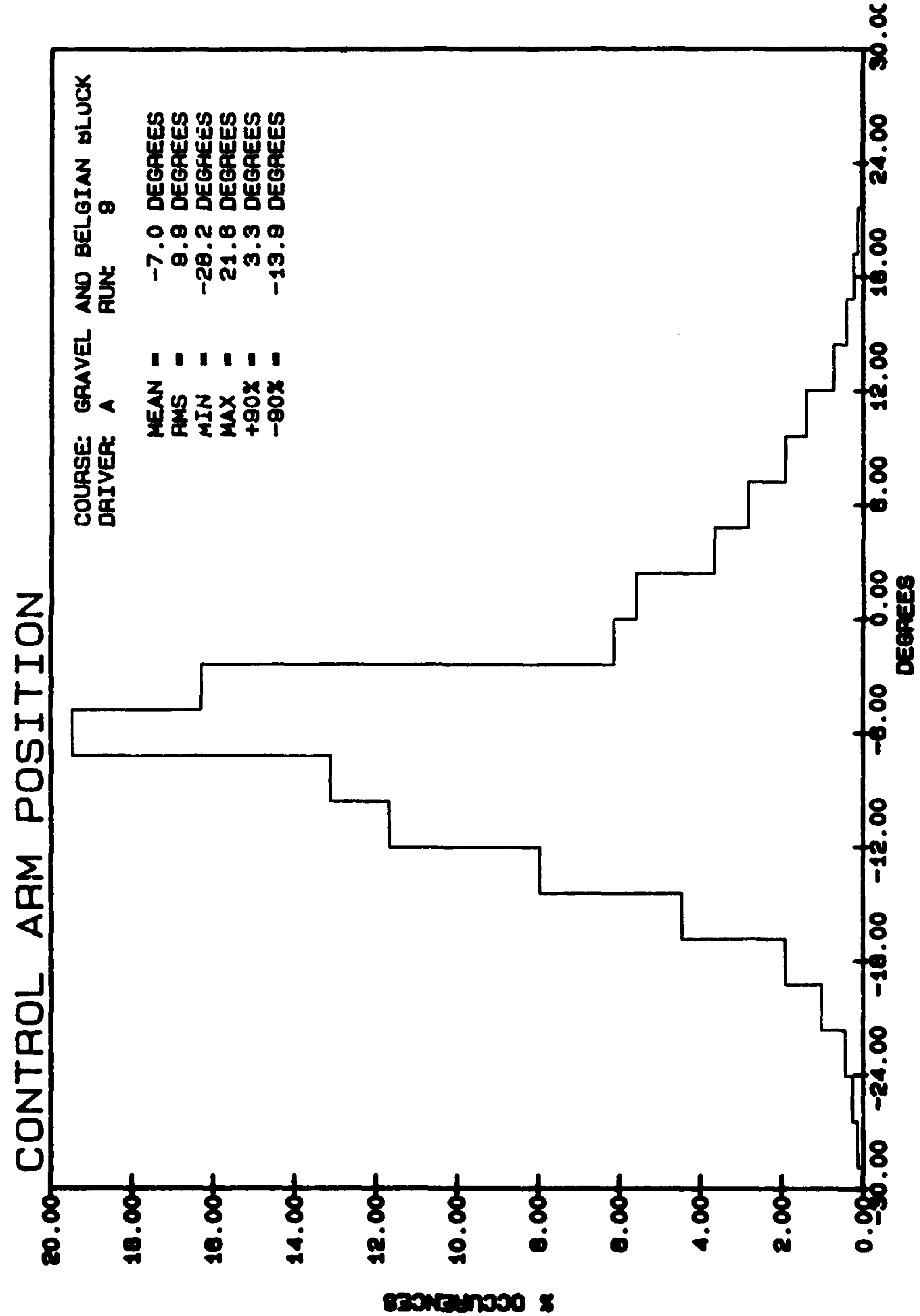


Figure 3-15. VPR generated histogram of control arm position.

3.1.3 (Cont'd)

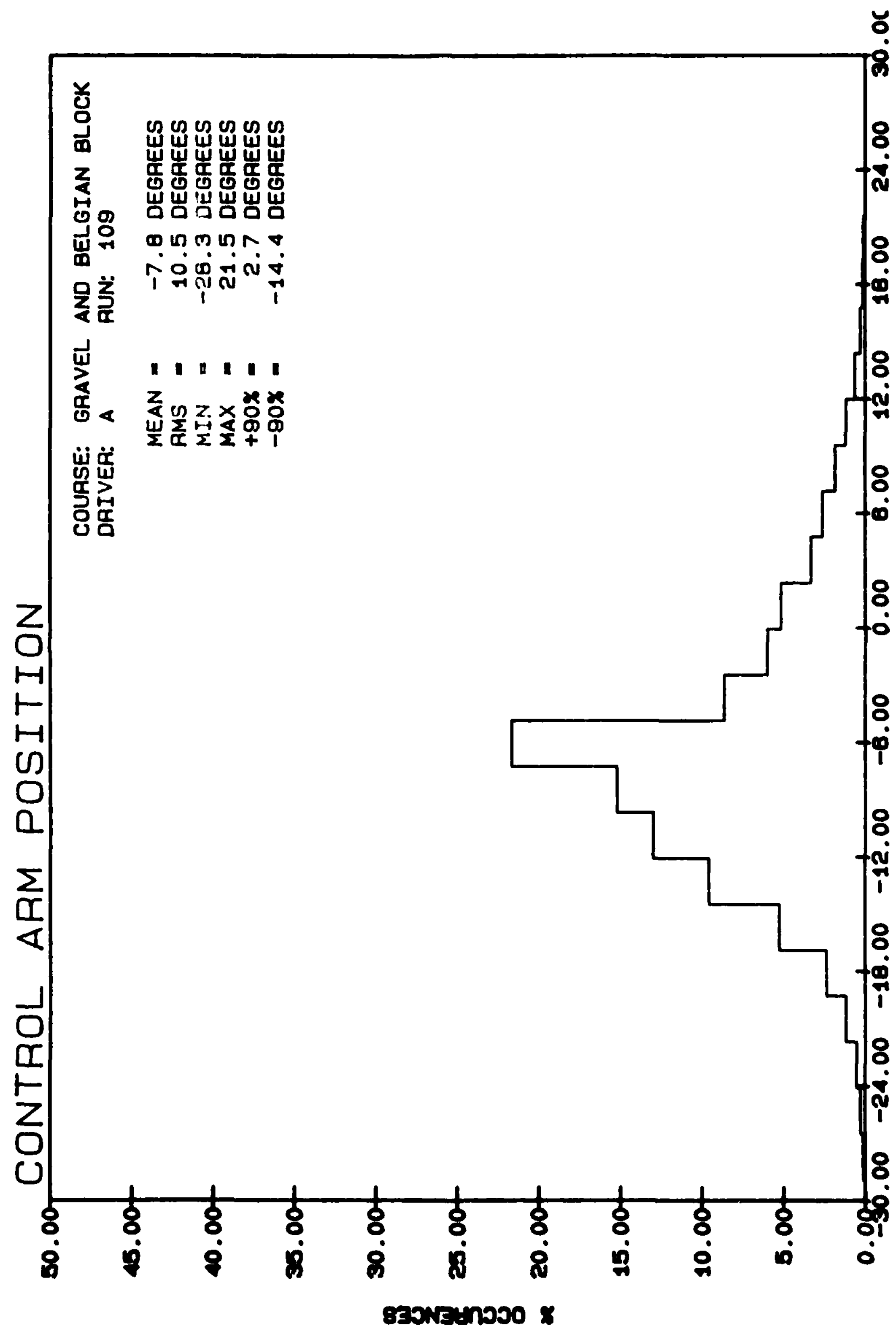


Figure 3-16. PCM generated histogram of control arm position.

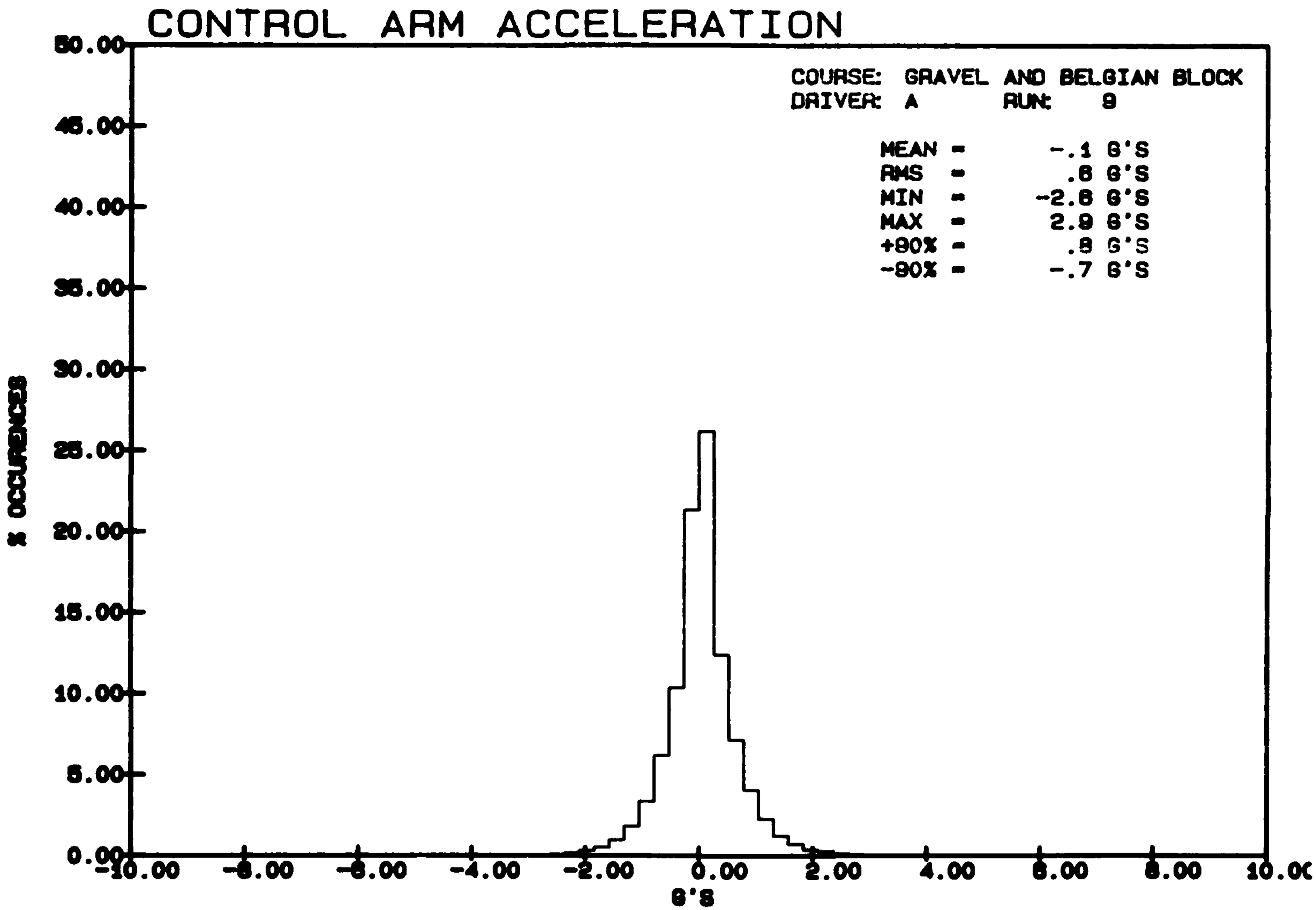


Figure 3-17. VPR generated histogram of control arm acceleration.

3.1.3 (Cont'd)

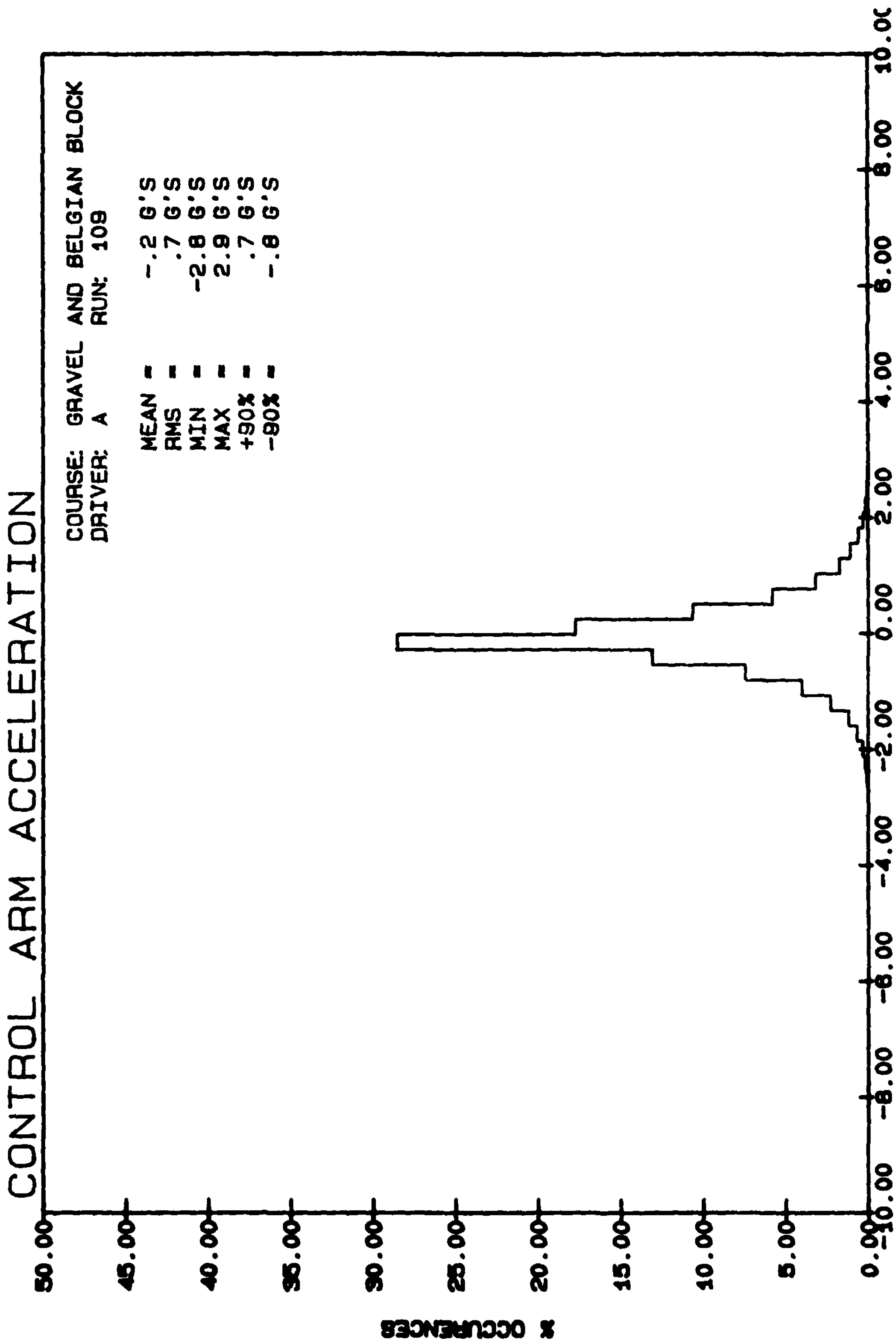


Figure 3-18. PCM generated histogram of control arm acceleration.

3.1.3 (Cont'd)

TABLE 3-2. INDEX OF COMPARATIVE HISTOGRAMS

Run	Test Course	Data Mode	Data Channel	Figure
107	Six-inch washboard	PCM	Control arm position	C-1
7	Six-inch washboard	VPR	Control arm position	B-7
109	Gravel and Belgian block	PCM	Control arm position	C-2
9	Gravel and Belgian block	VPR	Control arm position	B-9
107	Six-inch washboard	PCM	Control arm acceleration	C-3
7	Six-inch washboard	VPR	Control arm acceleration	B-13
109	Gravel and Belgian block	PCM	Control arm acceleration	C-4
9	Gravel and Belgian Block	VPR	Control arm acceleration	B-20
113	Cross country 3	PCM	Control arm acceleration	C-5
13	Cross country 3	VPR	Control arm acceleration	B-22
107	Six-inch washboard	PCM	Road speed	C-6
7	Six-inch washboard	VPR	Road speed	B-26
109	Gravel and Belgian block	PCM	Road speed	C-7
9	Gravel and Belgian block	VPR	Road speed	B-33
113	Cross country 3	PCM	Road speed	C-8
13	Cross country 3	VPR	Road speed	B-35
107	Six-inch washboard	PCM	Engine speed	C-9
7	Six-inch washboard	VPR	Engine speed	B-39
109	Gravel and Belgian block	PCM	Engine speed	C-10
9	Gravel and Belgian block	VPR	Engine speed	B-48

3.1.4 Analysis

For the purposes of the testing described in this report, analysis of data is directed toward answering four questions. These questions are:

a. Are the sampling rates used adequate?

b. Do the VPR generated histograms reflect the underlying sample distribution functions of the measurements being made?

c. Is the desired information concerning test course and driver input contained in the histograms?

d. Does the VPR adequately record the road and engine speed time histories to be considered as a tachograph replacement?

Time history data from run 9 are presented graphically in Figure 3-9 through 3-12 to indicate the waveshape of the data and to illustrate the futility of using time history data for analysis. The data represents approximately 6 seconds of a 15 minute data run. To compress the data in plot form would obscure the data and to present the entire run would require 150 pages per channel. The only information available from data in this format are extreme values. The histogram, in addition to providing a compact means for data storage, provides useful statistical information about the data. The time history data from the road speed channel show noise present in the data. Examination of other data runs indicate that this occurs when the vehicle is subject to vibration. This problem was localized to the PCM system, and for the purposes here can be ignored.

In order to check the adequacy of the low pass filters of the control arm potentiometer and accelerometer (25 Hz), and to determine the frequency content of the data, the percent of energy in various frequency bands for the control arm position and acceleration were computed and are presented in Table 3-3. The data were obtained by integrating the PSD's from run 109 (the largest frequency spread) over the frequency bands of interest.

TABLE 3-3. PERCENT OF ENERGY IN VARIOUS FREQUENCY BANDS

Frequency Band, Hz	Position	Acceleration
0-5	95.4	32.1
0-10	99.2	69.6
0-15	100.0	94.6
0-20	100.0	98.2
0-25	100.0	100.0

3.1.4 (cont'd)

An examination of the PSD's of the parameters measured over several of the data runs reveals that the sampling rates used (50 and 5 Hz) are adequate in all cases. The only parameter approaching a problem area is the control arm acceleration. Using the analysis presented in Reference 1, a worst case RMS aliasing error of 3% can be expected.

A visual examination of corresponding pairs of histograms for each of the runs and each of the channel indicates that, generally, the shape of the PCM and VPR histograms and thus the probability distributions of the data are the same. The data from run 7 (6-inch washboard) do not appear identical visually because of a time skew between the data sets for these runs. The VPR data collection process was started a considerable time before the PCM process while the vehicle was at rest awaiting the start of the run (Figures B-26 and C-6, data at 0 mph). The result was that the two data populations were not the same (a considerable amount of zero data were recorded by the VPR) and this was reflected in the general shape of the corresponding histograms.

The statistical information generated from the histograms was summarized by computing the ratio of the VPR values to the PCM values for the mean, rms, range (max-min), and 80% range (-90% - +90%) values. These ratios were then averaged for each data channel and are tabulated in Table 3-4. Detailed data are presented in Appendix D. All the average ratios show that the VPR and PCM statistical data agree within $\pm$ 5%. These differences can be attributed to lack of synchronization between the two acquisition strategies.

TABLE 3-4. AVERAGE VALUE RATIO (VPR/PCM)

Channel	Ratio
Control arm position	0.946
Control arm acceleration	0.958
Road speed	0.964
Engine speed	1.020

3.1.4 (Cont'd)

Table 3-5 is a compilation of the statistics derived from the VPR calculated histograms. It should be noted that during the two days of testing that was accomplished two skilled, professional drivers were used and that their instructions were to drive in a normal manner. It had been planned to subject the vehicle to varying levels of stress (ranging up to abuse), but these plans were not carried out due to a vehicle failure. Even under these conditions the following observations can be made:

a. The transmission temperature difference is significantly different for the three test courses. Section 3.4 should be consulted for a more detailed discussion of this parameter.

b. The control arm position data differentiate between the gravel/Belgian block and the 6 inch washboard courses. Unfortunately, the transducer slipped prior to the Perryman testing.

c. The road and engine speed statistics vary from driver to driver and from course to course.

d. No significant variations (either course or driver related) are discernible in the control arm acceleration data and thus its usefulness is questionable. This problem will be addressed by collecting more data on a similarly suspended vehicle in the near future.

3.1.4 (Cont'd)

TABLE 3-5. STATISTICS DERIVED FROM THE VPR HISTOGRAMS

Channel	Course	Driver	Run	Mean	Rms	Min	Max	+90%	-90%
TTD	GBB	B	1	45.0	45.2	18.8	59.8	51.4	43.2
TTD	GBB	B	2	45.0	45.1	39.0	49.5	49.0	43.6
TTD	GBB	B	3	41.4	41.5	31.9	49.5	47.3	37.9
TTD	GBB	B	4	43.8	44.3	21.5	58.3	51.8	38.0
TTD	GBB	B	5	51.2	51.3	46.3	60.0	56.0	50.1
TTD	WB	A	7	38.0	38.2	31.9	45.9	44.6	35.9
TTD	GBB	A	8	45.4	45.5	32.0	53.0	49.9	44.0
TTD	GBB	A	9	45.5	45.7	28.6	58.4	51.7	43.4
TTD	GBB	A	10	50.6	50.7	25.1	57.0	55.9	49.5
TTD	HW	A	11	48.5	48.9	35.4	60.0	58.5	40.4
TTD	CC3	A	12	36.5	37.0	17.9	49.4	46.0	29.3
TTD	CC3	A	13	32.3	33.0	10.7	45.3	40.1	28 4
CAP	GBB	B	1	-4.5	7.8	-25.5	20.8	4.2	-10.5
CAP	GBB	B	2	-4.4	7.9	-25.8	21.4	5.2	-10.9
CAP	GBB	B	3	-4.8	6.2	-23.8	12.9	.4	-7.9
CAP	GBB	B	4	-4.1	6.6	-23.6	18.3	2.9	-8.9
CAP	GBB	B	5	-3.9	6.8	-24.0	20.5	4.0	-9.0
CAP	GBB	B	6	-3.9	6.6	-23.2	20.7	3.8	-8.8
CAP	WB	B	7	-6.5	12.8	-38.4	31.5	6.1	-23.3
CAP	GBB	A	8	-4.4	8.8	-24.7	28.9	7.0	-11.8
CAP	GBB	A	9	-7.0	9.9	-28.2	21.6	3.3	-13.9
CAP	GBB	A	10	-10.5	14.2	-37.5	22.0	2.3	-21.1
CAP	HW	A	11	-8.2	8.9	-19.7	11.9	-3.2	-10.9
CAP	CC3	A	12	-29.1	33.1	-69.9	6.8	-3.8	-47.1
CAP	CC3	A	13	-17.3	25.7	-59.1	34.6	6.8	-45.1
CAA	GBB	B	1	-.1	.8	-2.5	2.9	.7	-.7
CAA	GBB	B	2	-.1	.7	-2.6	2.9	.8	-.7
CAA	GBB	B	3	-.1	.3	-1.2	1.3	.3	-.3
CAA	GBB	B	4	-.1	.6	-2.4	2.6	.6	-.6
CAA	GBB	B	5	-.1	.6	-2.5	2.6	.7	-.7
CAA	GBB	B	6	-.1	.6	-2.5	2.9	.7	-.6
CAA	WB	A	7	-.1	.6	-2.2	3.9	.9	-.6
CAA	GBB	A	8	-.1	.6	-2.6	2.8	.7	-.7
CAA	GBB	A	9	-.1	.6	-2.6	2.9	.8	-.7
CAA	GBB	A	10	-.1	.6	-2.6	2.8	.8	-.7
CAA	HW	A	11	-.1	.3	-1.0	1.1	.5	-.4
CAA	CC3	A	12	-.1	.5	-1.8	2.0	.8	-.5
CAA	CC3	A	13	-.1	.5	-1.9	2.0	.7	-.8

3.1.4 (Cont'd)

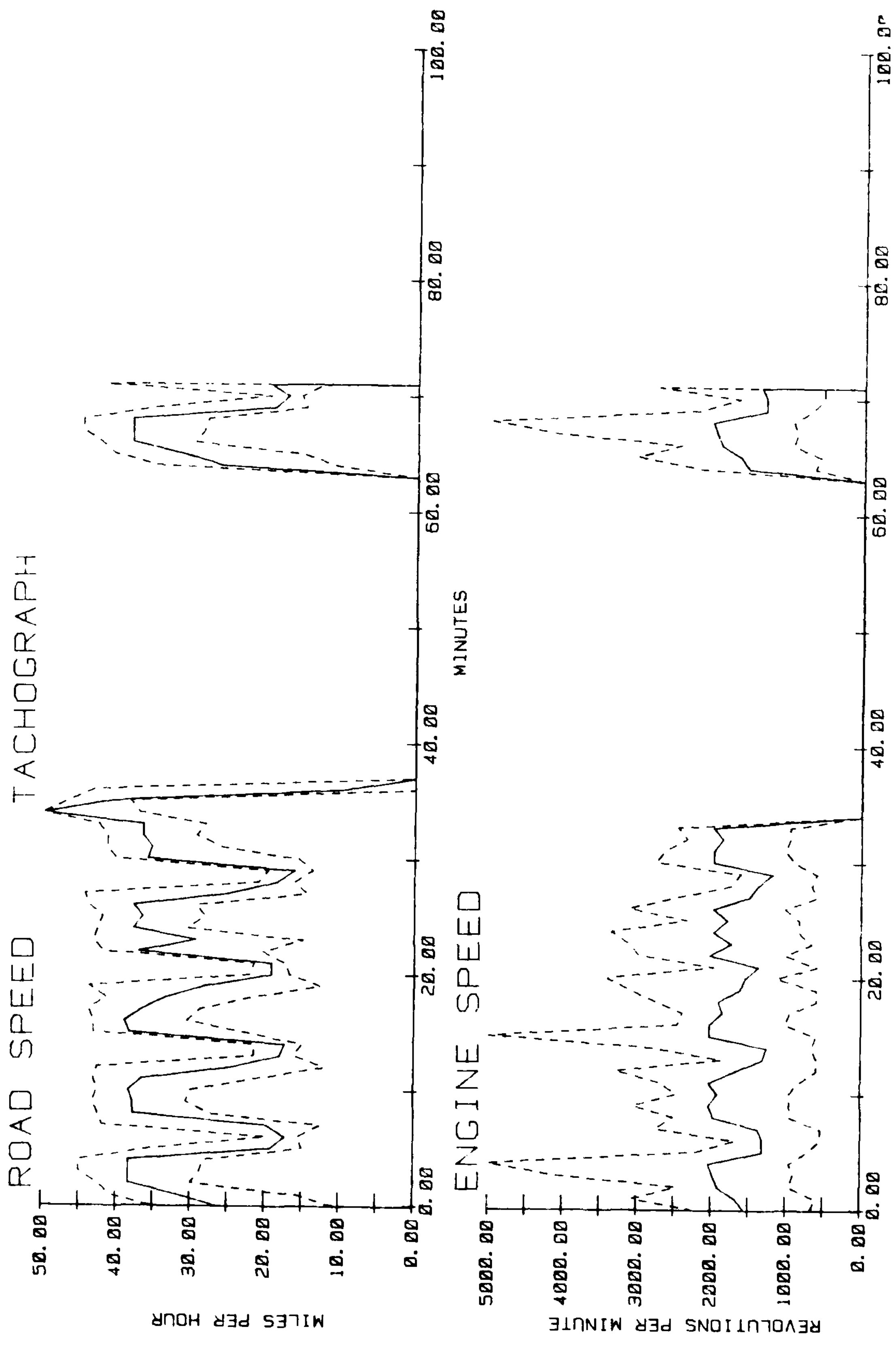
TABLE 3-5 (CONT'D)

Channel	Course	Driver	Run	Mean	Rms	Min	Max	+90%	-90%
RS	GBB	B	1	27.9	28.9	.1	40.2	38.7	18.7
RS	GBB	B	2	28.4	29.1	14.3	40.3	36.6	20.4
RS	GBB	B	3	20.5	23.0	.0	35.5	32.6	1.0
RS	GBB	B	4	23.9	25.1	.0	42.4	33.5	17.9
RS	GBB	B	5	25.6	26.2	9.2	38.0	32.5	19.1
RS	GBB	B	6	25.3	26.0	3.9	37.9	32.9	18.3
RS	WB	A	7	3.9	4.9	.0	16.3	5.9	.5
RS	GBB	A	8	32.4	33.6	.0	42.9	40.4	21.1
RS	GBB	A	9	25.4	28.8	.0	42.2	38.9	.8
RS	GBB	A	10	29.4	30.7	.1	44.8	39.8	19.4
RS	HW	A	11	39.0	41.0	.0	50.3	47.9	19.4
RS	CC3	A	12	11.2	12.9	.0	25.6	17.5	.6
RS	CC3	A	13	14.0	15.2	.0	31.5	18.8	1.7
ES	GBB	B	1	1540	1584	596	2408	2133	1080
ES	GBB	B	2	1535	1579	619	2373	2122	1103
ES	GBB	B	3	1275	1351	443	2135	1947	746
ES	GBB	B	4	1380	1429	530	2446	1950	928
ES	GBB	B	5	1417	1451	603	2226	1909	1059
ES	GBB	B	6	1389	1431	537	2141	1900	955
ES	WB	A	7	892	927	382	2230	1090	741
ES	GBB	A	8	1938	1985	619	4337	2416	1554
ES	GBB	A	9	1839	1720	475	3456	2279	841
ES	GBB	A	10	1760	1810	646	3809	2329	1322

TTD = Transmission temperature differential in degrees Centigrade
CAP = Control arm position in angular degrees
CAA = Control arm acceleration in g's
RS = Road speed in mph
ES = Engine speed in rpm
GBB = Gravel and Belgian block
WB = 6-inch washboard
HW = Highway
CC3 = Cross-country 3

3.1.4 (Cont'd)

Figure 3-19 is a representative plot of the road and engine speeds collected by the VPR. All other time histories are in Appendix D. An examination of the VPR and PCM time histories shows good agreement (after the time axis has been properly alined). These plots consist of the average, maximum, and minimum speeds achieved during each one minute time cell. To aid readability the plots of maximum and minimum values can be suppressed. The processing software also includes a zoom feature to allow any time slice to be isolated.


ROAD SPEED
TACHOGRAPH
MILES PER HOUR
50.00
40.00
30.00
20.00
10.00
0.00
0.00
20.00
40.00
60.00
80.00
100.00
MINUTES
ENGINE SPEED
REVOLUTIONS PER MINUTE
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
20.00
40.00
60.00
80.00
MINUTES

3.2 Drive Train Load Parameter Test

A drive train load parameter test was performed to determine and verify a drive train load indicator to be used during the endurance portion of the IPT of HMMWV. A load indicating parameter should satisfy the following criteria:

a. Provide repeatable results that correlate well with drive train load under endurance test conditions.

b. Be durable in the endurance environment.

c. Cause minimum disturbance or alteration to the vehicle during installation and operation.

d. Be quickly and easily installed.

3.2.1 Data Acquisition Procedure

Exhaust gas temperatures and transmission oil temperature were considered possible load indicators. To verify the correlation of these load indicating parameters, limited resistance to tow, road load and full load tests (app J, ref 4 and 5) were conducted on the APG Dynamometer Course. In an effort to save time (with little sacrifice in accuracy) drive shaft torque was computed from drawbar pull instead of using instrumented shafts. Chromel-alumel thermocouples were installed on the outside surfaces of the left and right exhaust gas collectors, on the left No. 2 and No. 4 exhaust headers and in the exhaust gas flow at the outlet end of the exhaust pipe. Copper-constantan thermocouples were installed in the line leading from the transmission to the cooler and in the airflow ahead of the cooler (to minimize effects of ambient air temperature changes). After limited testing, it appeared that the transmission temperature differential provided the best correlation with the computed torque, and more effort was directed toward testing transmission oil temperature as the load indicating parameter.

To establish a drive train load - oil temperature relationship it was first necessary to determine a resistance to tow curve. These data were acquired by measuring the actual drawbar load required to tow the HMMWV with the rear load cell of a mobile field dynamometer. Towing resistance was measured at 5 mph increments from 5 to 45 mph under the condition described in Appendix H, Table H-2. After determining resistance to tow, the vehicle was connected to the front load cell of the dynamometer. Then a full-load, high range, first gear drawbar pull curve was run from stall to 32 mph. Vehicle test conditions remained the same as during resistance to tow, except that the vehicle was operating at full throttle in first gear. At each road speed the engine rpm, drawbar pull and approximate steady state transmission temperature differential were recorded. Part-throttle temperatures for high range, first gear operation were measured at 5 mph intervals up to 40 mph during road-load testing. The torque loading for each speed and temperature was computed from the resistance to tow at these speeds.

Once the torque-temperature relationship was established, the VPR was installed in the vehicle and the thermocouples were replaced by resistance temperature devices (RTD). The VPR recorded the transmission temperature differential during 250 miles of operation on various Munson and Perryman test courses. Histograms of this testing are presented in Appendix B.

3.2.2 Results

Drive shaft torques were computed from actual dynamometer loads. Table 3-6 presents the actual resistance to tow and computed equivalent drive shaft torque for testing conducted under the conditions described in Appendix H, Table H-2.

TABLE 3-6. HMMWV RESISTANCE TO TOW CHARACTERISTICS

Vehicle Road Speed (mph)	Actual Towing Resistance Load (lb)	Calculated Drive Shaft Torque (ft-lb)
5	134	38
10	154	43
15	178	50
20	178	57
25	216	61
30	211	60
35	236	67
40	247	70
45	259	73

Computed drive shaft torques and steady state transmission temperature differentials from the full load and road load testing are presented in Table 3-7 and graphically in Figure 3-20. Field data and details of the torque calculation are presented in Appendix H.

3.2.? (Cont'd)

TABLE 3-7. HMMWV DRIVE SHAFT TORQUE TEMPERATURE CHARACTERISTICS

Computed Drive Shaft Torque (ft-lb)	Transmission Temperature Differential (°F)
954	216
883	169
823	187
786	188
661	168
585	125
480	130
478	131
490	122
322	120
70	74
61	67
60	68
57	70
50	59
43	47
38	49

3.2.2 (Cont'd)

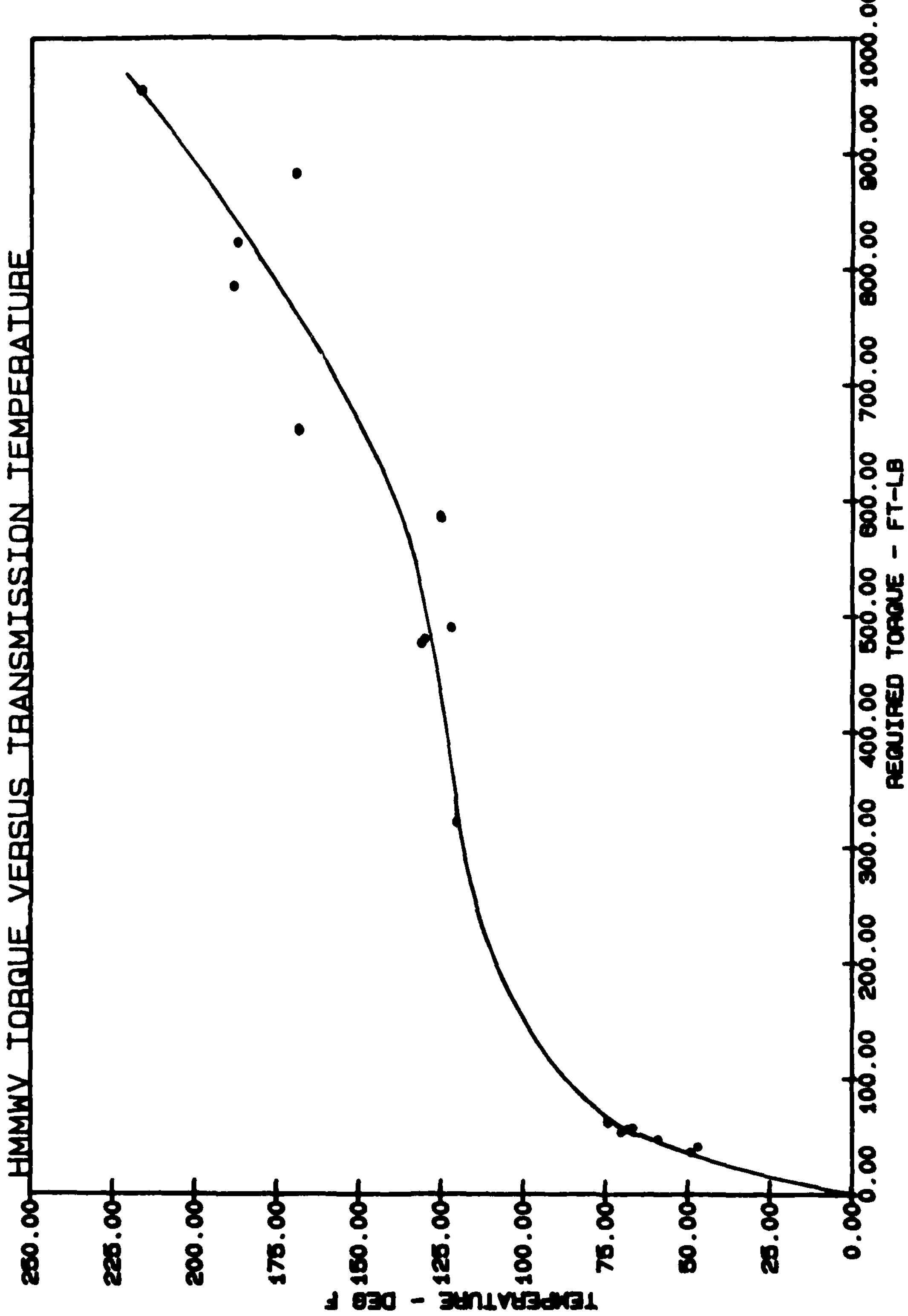


Figure 3-20. Torque-temperature relationship.

3.2.3 Analysis

To verify the resistance to tow and drawbar pull curves resulting from this test, a comparison was made with the similiar curves from HMMWV Developmental Testing (DT) (app J, ref 6). Figure 3-21 shows that the computed resistance to tow torque is less than the resistance to propulsion determined during DT, but both curves show the same trend. There are three possible factors contributing to this decreased resistance:

a. The tire pressure has been increased from 15 to 22 psi, resulting in reduced rolling resistance.

b. The present tests were carried out with a dynamometer in front of the HMMWV, resulting in decreased wind resistance.

c. The inefficiency of the drive trains could not be included in the resistance to tow calculations.

The decrease in drawbar pull and drive shaft torque, shown in Figures 3-22 and 3-23 respectively, can be attributed to two major factors:

a. The differential gear ratio was changed from 2.73:1 during DT to 2.56:1.

b. The characteristics of the hybrid transmission used in the VPR vehicle.

From these comparisons made with HMMWV Developmental Test data, confidence can be placed in the validity of the curves generated by the current tests. It should be realized ,moreover, that the differences are not critical in that during endurance testing the data will be used in a comparative manner, rather than to determine exact engineering performance characteristics.

General performance curves for a hydrodynamic torque converter are presented in Figure F-3 (app F). Power lost in the converter due to inefficiency is absorbed by the oil. Therefore the oil temperature will increase with the demand for torque (high torque ratio). Figure 3-20 shows this relationshp between torque demand and transmission oil temperature. The temperatures indicated on this plot were recorded after they had achieved a steady state, which required approximately 40 seconds.

Examination of the transmission temperature histograms developed by the VPR during the 250 miles of operation show some interesting developments.

Comparison of two different drivers on the same Munson course, shows only minor differences in the indicated torque demand. Road speed histograms developed from the same data sets, indicate that similar torque demands would be expected.

Another observation was that the Perryman highway temperature histogram showed a higher indicated torque demand than for Munson gravel. A feasible explanation of this apparent erroneous indication is the significantly increased cooling airflow decreasing the ambient temperature.

3.2.3 (Cont'd)

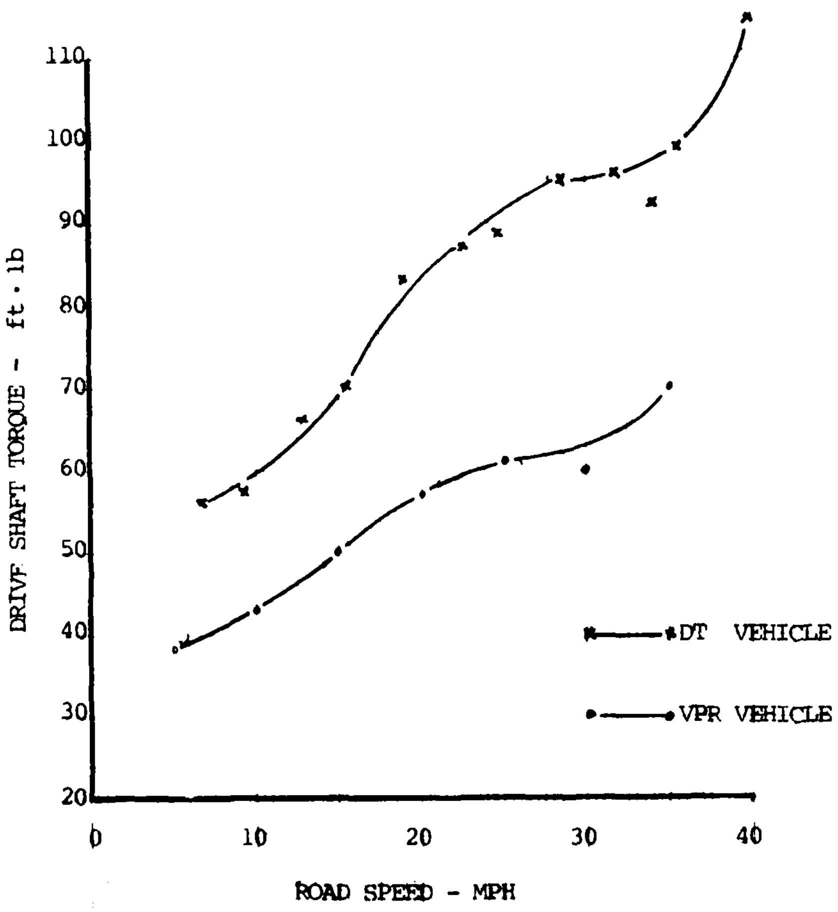


Figure 3-21. DT vehicle resistance to propulsion and VPR vehicle resistance to tow.

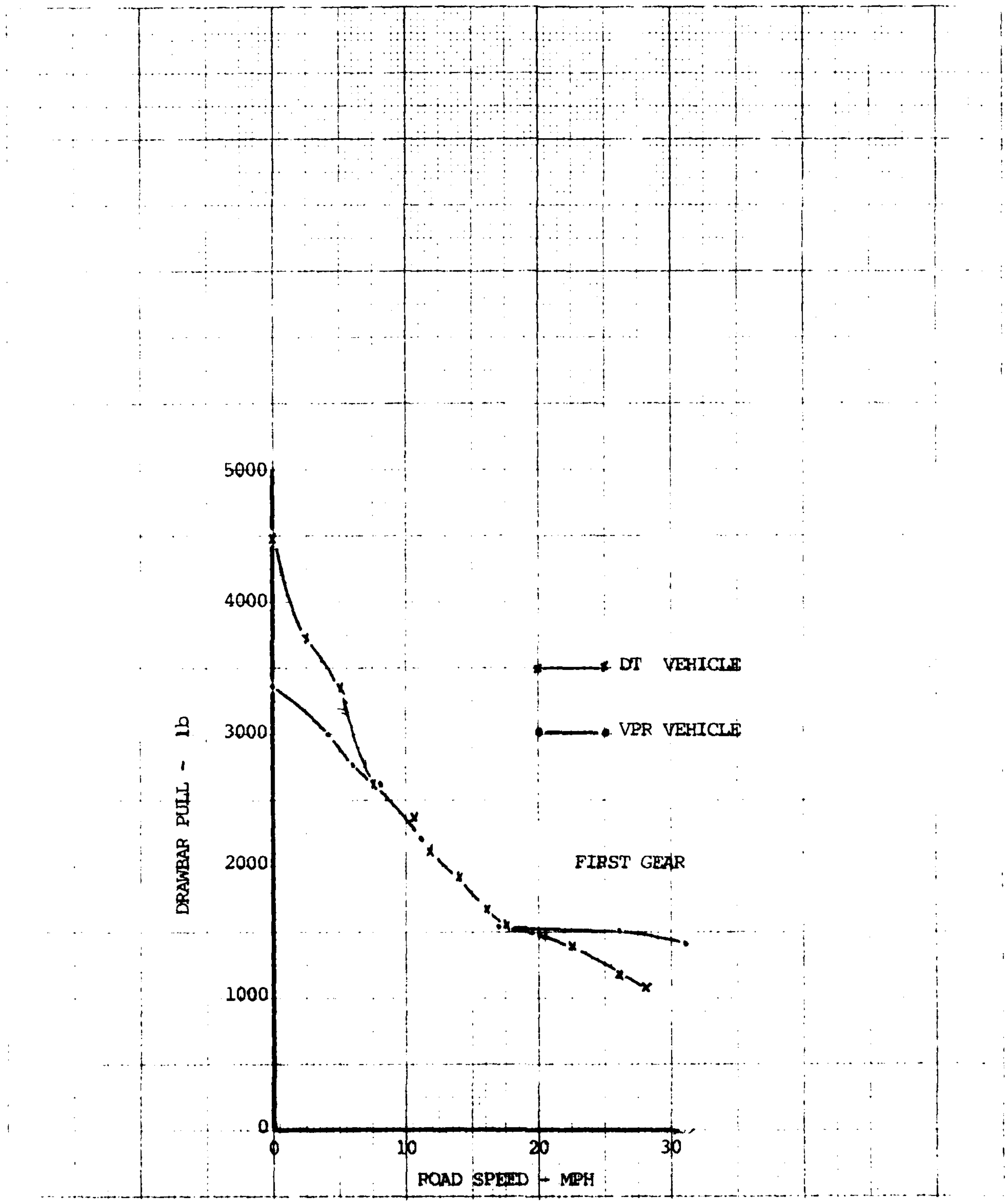


Figure 3-22. Drawbar pull - high range.

3.2.3 (Cont'd)

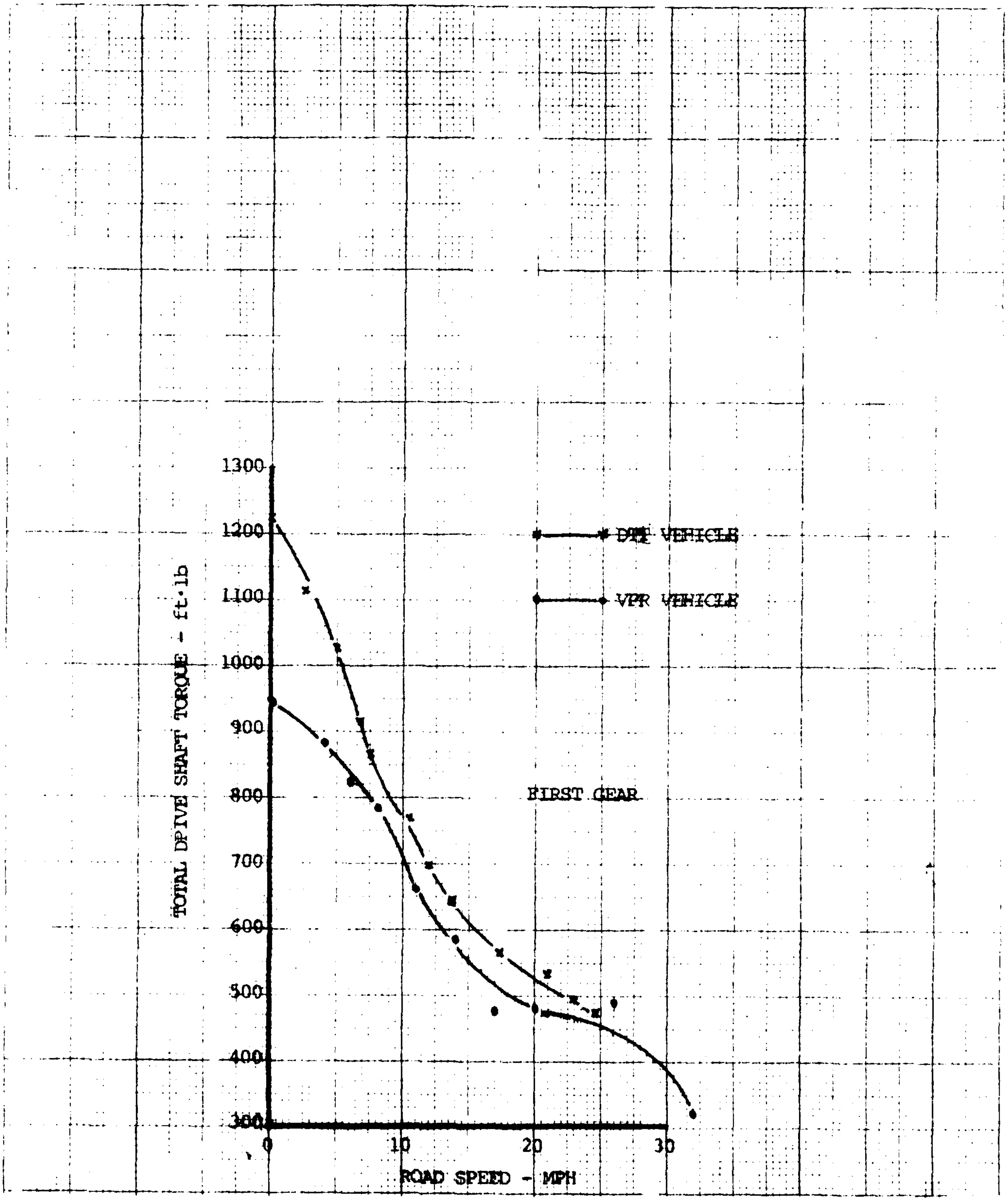


Figure 3-23. Total drive shaft torque - high range - full load.

3.2.3 (cont'd)

Perryman cross-country 3 course temperature histogram indicates that the torque demand was similar to Munson gravel operation, which seems unreasonable. Upon investigation it was determined that the driver was operating in Low Range on the Perryman course. Low Range reduces the torque demand by 62%, therefore the transmission temperature is probably an indication of the true torque demand of the converter.

It is recommended that additional road testing into the use of transmission oil temperature be performed before the upcoming endurance portion of HMMWV Initial Production Test. During this additional testing, a specific recommendation is that the RTD in the airflow ahead of the cooler be placed in the oil return line out of the cooler. Also, an additional VPR channel should be used to indicate High or Low transfer position. This would allow the indicated torque to be scaled to represent the true torque necessary at the axles to propel the vehicle. The exhaust gas temperatures should be further investigated at the same time.

4. CONCLUSIONS

VPR/HMMWV interface verification testing was carried out over a two day period and comprised approximately 250 miles of road tests. Testing was terminated as a result of a vehicle failure, and consequently the degree of confidence in the results is not as high as it could have been. The following conclusions can be drawn from the testing which was accomplished:

a. The VPR can be utilized to monitor and record the operator and test course inputs during the endurance phase of the IPT of HMMWV.

b. With the exception of the control arm position potentiometer, the transducer mounting techniques have been validated. The control arm position potentiometer mounting requires some modifications to prevent slippage and interference from mud buildup.

c. The appropriateness of the parameters being measured was not fully established. During the abbreviated testing only four test courses and two drivers were used, and no testing was attempted in what would be considered a stressful manner. However, the data collected does indicate differences between drivers and test courses.

5. RECOMMENDATIONS

It is recommended that:

a. The VPR be used during the endurance portion of the IPT of HMMWV to monitor the test course and operator inputs to the vehicle system.

b. The VPR be used to perform the tachograph function during the endurance portion of the IPT of HMMWV.

c. The parameters (1) control arm position, (2) control arm acceleration, (3) transmission fluid temperature, (4) engine speed, (5) road speed, (6) number of brake applications, (7) accumulated times brakes applied, and (8) the ratio of engine and road speed (gear) be measured and processed into histograms to provide an overall statistical description of the endurance test portion of the IPT of HMMWV. Investigation of these parameters should continue, however.

d. Investigation into the question of a surrogate for delivered torque or engine output power be continued. (To support this effort a commercial utility cargo vehicle [CUCV], which uses the same engine as the HMMWV, has been made available.)

e. Investigation into the suspension related parameters (control arm position and acceleration) be continued to assure that the maximum information regarding test course inputs be extracted.

f. The control arm position potentiometer mounting bracket be modified to prevent slippage and interference from mud buildup.

g. TECOM funding be provided for follow-up development of the VPR, and for the related methodology.

APPENDIX A - HISTOGRAMS

One way to monitor a process is to record time histories pertinent to the process and at some point in time look at this recorded data (e.g., through plots or listings). For large sets of data this is tedious, time consuming, expensive, probably fruitless, and requires a large storage capability. For example, if three parameters are sampled and recorded 50 times per second and three are sampled and recorded five times per second, at the end of a 12 hour period over seven million samples would be saved. Clearly some technique which preserves the intelligence borne by these parameters, but which reduces the information to an understandable form and to a reasonable volume must be used.

A histogram is computed in the following manner (app J, ref 2 and 3):

a. An interval of the range of the parameter x, say $a<x<b$, is subdivided into k subintervals (or bins) of equal length so that the entire range of x is broken up into (k + 2) intervals. ($x < a$, the k bins, and $x > b$).

b. All data associated with the parameter are examined, and the number of occurrences in each interval are tabulated.

c. A plot of the number of occurrences N_j for each interval j is generated, or alternately a normalized plot of $100 *(N_j/N)$ (where N is the total number of samples) may be used.

Figure A-1 shows a typical histogram.

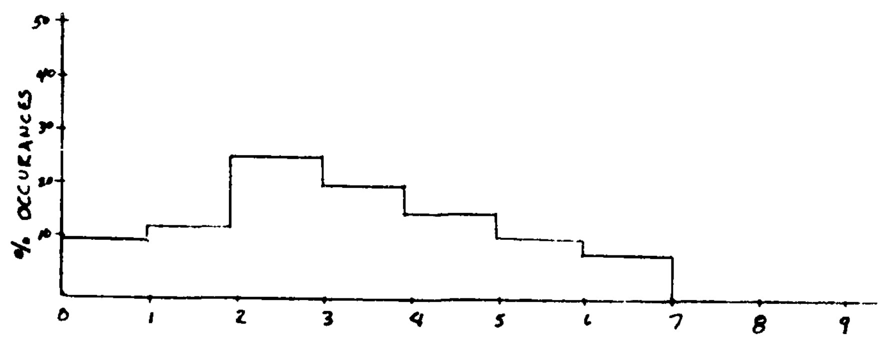


Figure A-1. Typical histogram.

From this figure, it can be seen that 10% of the time x takes on values between 0 and 1, 12% of the time between 1 and 2, 25% of the time between 2 and 3 etc.

Histograms are closely related to the probability density function of the underlying process. This sample density function is not unique for a given data group, however, but also depends on other factors such as the number and width of the bins used and the number of data samples included in the histogram generation. Even with this lack of uniqueness, histograms are generally treated as sample probability density functions.

A histogram can yield valuable key information. The sample mean can be calculated by:

$$\bar{X} = \frac{1}{N} \sum N_J X_J$$

and the RMS level by

$$RMS = \sqrt{\frac{1}{N} \sum N_J X_J^2}$$

where N_j is the value of the jth bin, and x_j is the corresponding value at the midpoint of the bin. The value x_j such that a fraction p of the measurements have a value $< x_j$ is given by

$$X_J \ni \sum_{k=1}^{J} N_k \leq (P/100) \cdot N \quad \text{and} \quad \sum_{k=1}^{J+1} N_k > (P/100) \cdot N$$

In this manner, the parameter value such that 90% of the measurements are lower (+90%) and 90% of the measurements are higher (-90%) are determined. The maximum and minimum values are similarily treated, and are determined by the ±99.9% occupation levels to prevent a spurious reading (or wild point) from being interpreted as these extreme values.

In the VPR, histogram processing is carried out in real time, with either a 50 or 5 time per second update rate. A new set of histograms is started each 30 minutes or upon operator intervention. At the end of each shift these data are transferred to a minicomputer where they are stored and plotted. The VPR has no facility to display the histograms.

Figure A-2 is the Pascal implementation of the histogram task which is executed in real time in the VPR. This task is scheduled at the completion of data input (every 20 msec). The histogram associated with pulse inputs is updated only 5 times per second.

```
 "Z80"
 PROGRAM HGRAM;
EXTENSIONS ON
SEPARATE ON
OPTIMIZE ON

 VAR
 BIN_I:              INTEGER;
 CH_I:               INTEGER;
 SEQ:                INTEGER;
 DVSOR:              INTEGER;
 HISTO_INR:          INTEGER;
 HISTO_OTR:          INTEGER;
 END_H:              BOOLEAN;
 EXIT:               BOOLEAN;
 MSG:                INTEGER;
 MAX_CH:             INTEGER;

GLOBVAR ON
 HISTO:              ARRAY[0..11519] OF INTEGER;
 OF_BUF:             ARRAY[0..179] OF INTEGER;
 SLICE_I:            INTEGER;
 START_T:            ARRAY[0..29] OF INTEGER;
 H_TBL:              ARRAY[0..5] OF INTEGER;
 OF_TBL:             ARRAY[0..5] OF INTEGER;
 DIV_TBL:            ARRAY[0..5] OF INTEGER;
 MUL_TBL:            ARRAY[0..5] OF INTEGER;
 MAJ_INDEX:          INTEGER;

EXTVAR ON
 DATA_BUF:           ARRAY[0..23] OF INTEGER;
 INCHAR:             CHAR;
 T_INDEX:            INTEGER;
 RET_CODE:           INTEGER;
 CNT_INC:            BYTE;

 CONST
 MIN_I     =  0;
 MAX_I     =  63;
 MAX_INT   =  32767;
 INR_LMT   =  1000;
 OTR_LMT   =  90;
 MAX_SLICE=  29;
 TMOUT     =  0;

 PROCEDURE SC_TSUSPEND(CODE:INTEGER;VAR RET_CODE:INTEGER);EXTERNAL;
 PROCEDURE SC_TDELETE(DLY:INTEGER;VAR RET_CODE:INTEGER);EXTERNAL;

 GLOBPROC ON
```

Figure A-2. VPR histogram task.

```
                         PROCEDURE HISTOGRM;
                              BEGIN
  IF (SLICE_I <= MAX_SLICE) THEN
    REPEAT
      SLICE_I:=SLICE_I+1;
      END_H:=FALSE;
      EXIT:=FALSE;
      HISTO_INR:=0;
      HISTO_OTR:=0;
      START_T[SLICE_I]:=T_INDEX;
      REPEAT
        MAJ_INDEX:=(SLICE_I)*384;
        REPEAT
          IF CNT_INC=2 THEN MAX_CH:=4
          ELSE MAX_CH:=2;
          FOR CH_I:=0 TO MAX_CH DO
            BEGIN
              SEQ:=H_TBL[CH_I];
              IF (SEQ>=0) THEN
                BEGIN
                  DVSOR:=DIV_TBL[CH_I];
                  BIN_I:=SHIFT((DATA_BUF[SEQ]+OF_TBL[CH_I]+1024),DVSOR);
                  IF(BIN_I > MAX_I)THEN BIN_I:=MAX_I;
                  IF(BIN_I < MIN_I)THEN BIN_I:=MIN_I;
                  BIN_I:=MAJ_INDEX+CH_I*64+BIN_I;
                  HISTO[BIN_I]:=HISTO[BIN_I]+1;
                END;
            END;
          SC_TSUSPEND(0,RET_CODE);
          IF (INCHAR="*") OR (INCHAR="?") THEN END_H:=TRUE;
          HISTO_INR:=HISTO_INR+1;
        UNTIL (HISTO_INR=INR_LMT) OR END_H;
        HISTO_INR:=0;
        HISTO_OTR:=HISTO_OTR+1;
      UNTIL (HISTO_OTR=OTR_LMT) OR END_H;
      IF (INCHAR="?") THEN EXIT:=TRUE;
    UNTIL (SLICE_I=MAX_SLICE+1) OR EXIT;
  SC_TDELETE(0,RET_CODE);
END;
```

Figure A-2. (Cont'd).

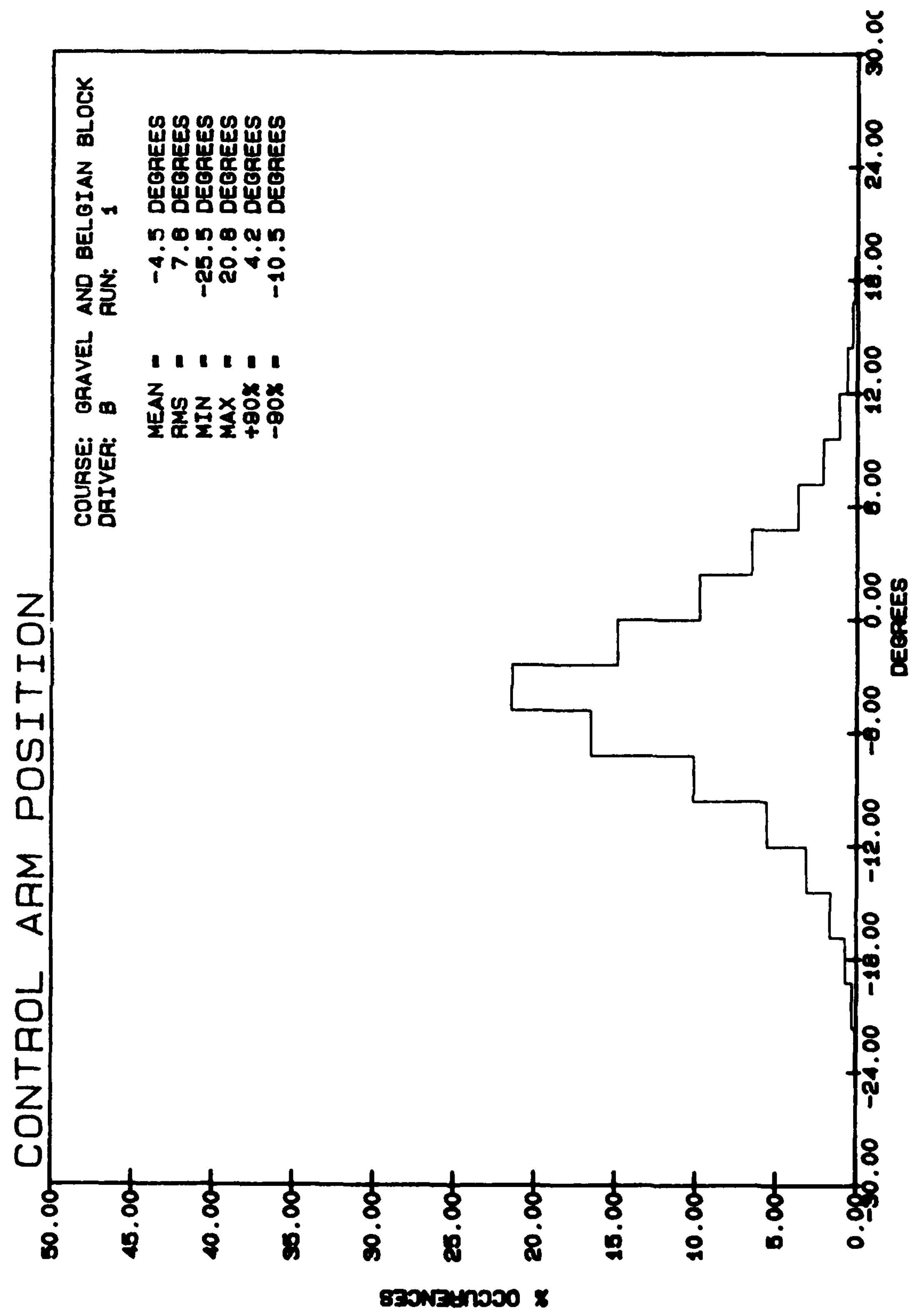

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 1
MEAN = -4.5 DEGREES
RMS = 7.8 DEGREES
MIN = -25.5 DEGREES
MAX = 20.8 DEGREES
+90% = 4.2 DEGREES
-90% = -10.5 DEGREES
DEGREES
% OCCURENCES

Figure B-1

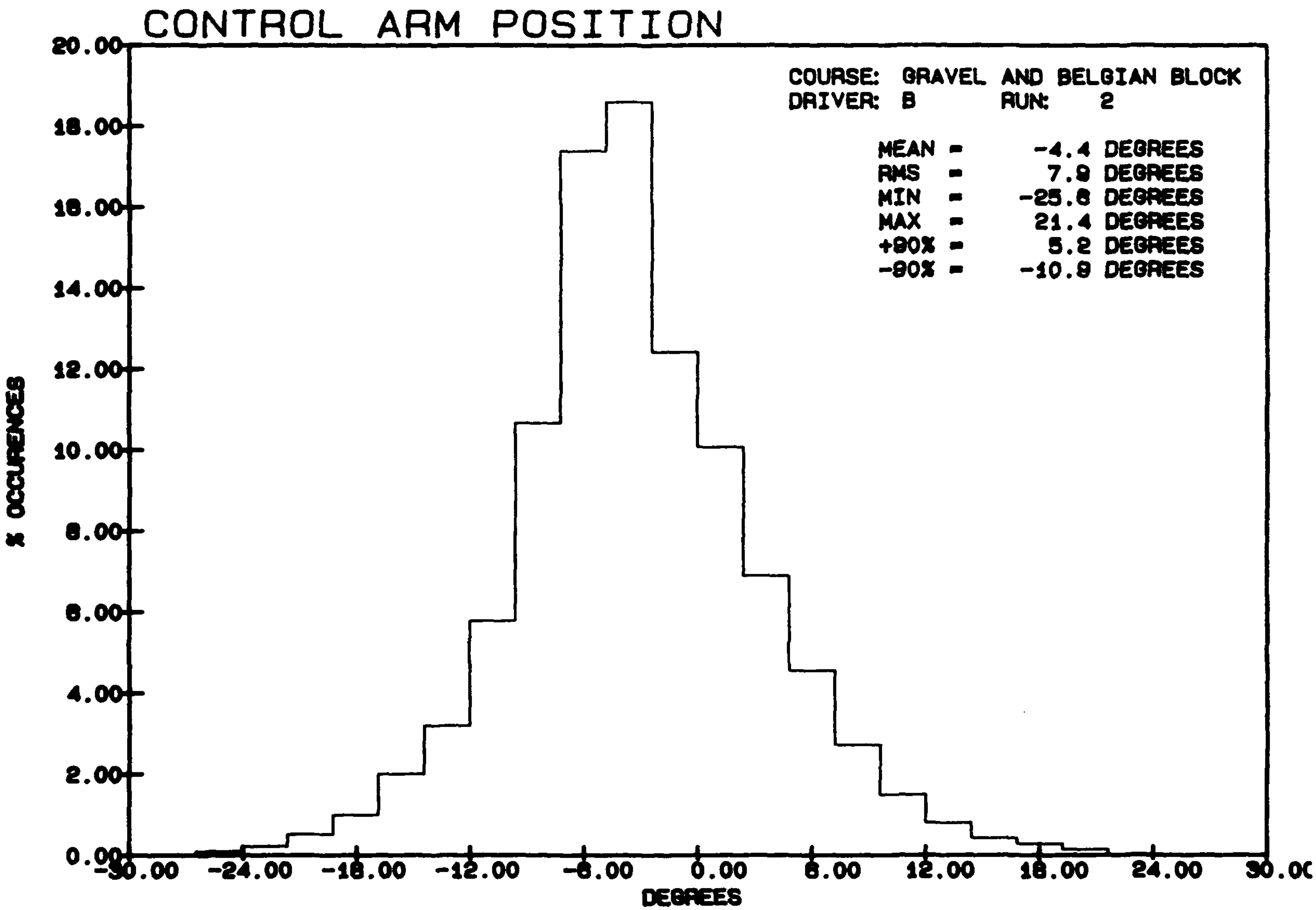

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 2
MEAN = -4.4 DEGREES
RMS = 7.9 DEGREES
MIN = -25.6 DEGREES
MAX = 21.4 DEGREES
+90% = 5.2 DEGREES
-90% = -10.9 DEGREES
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00
DEGREES

Figure B-2

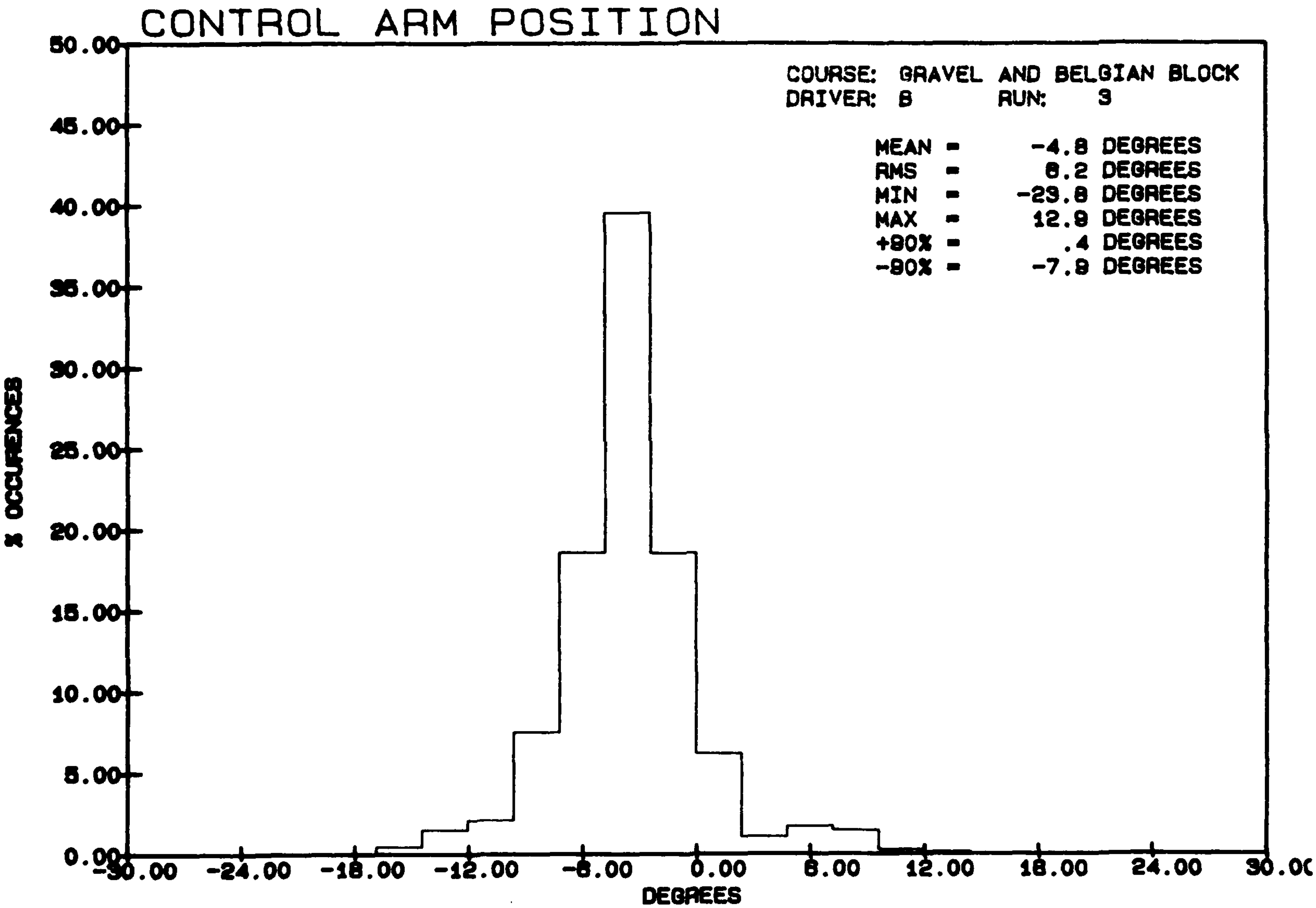
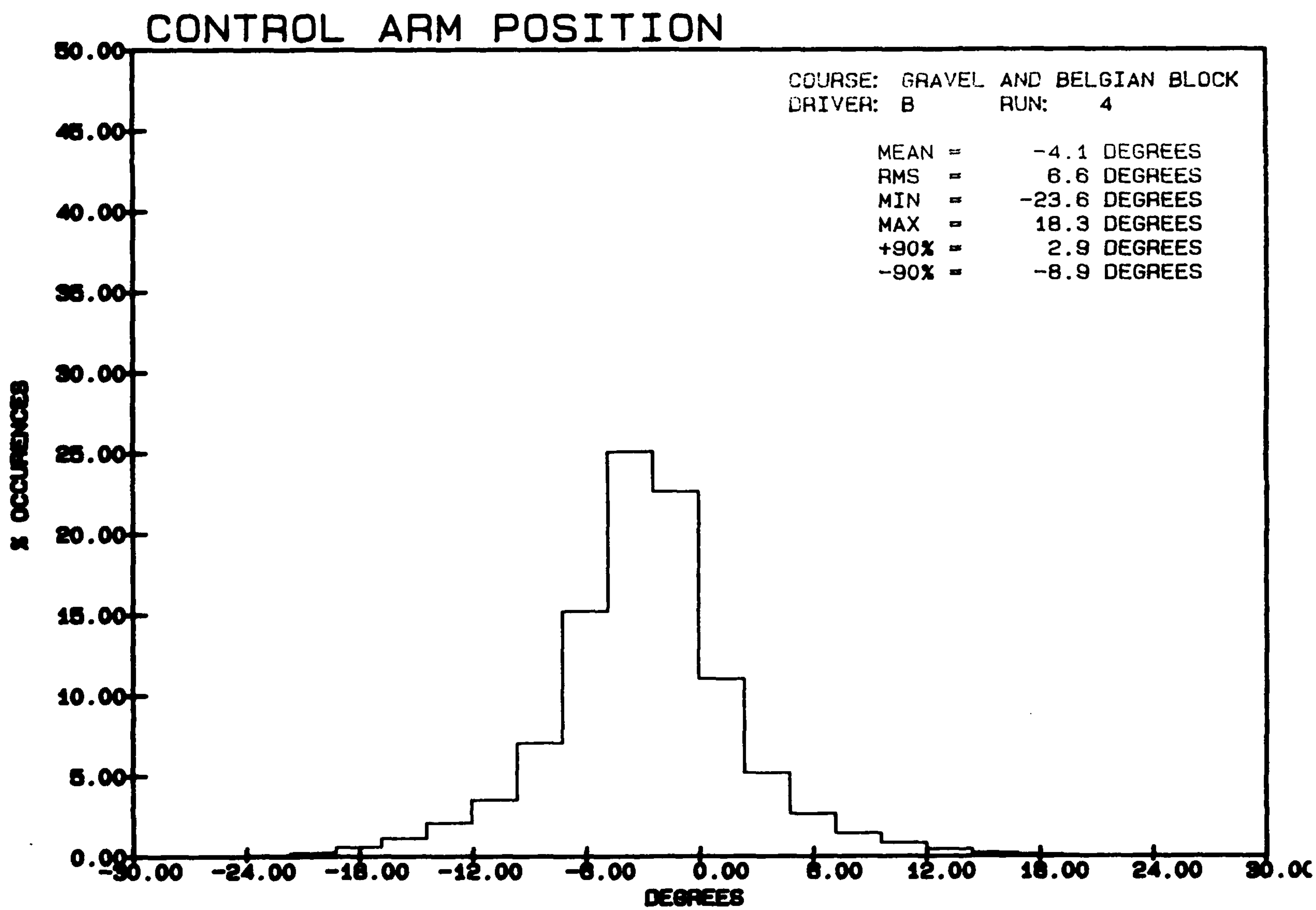

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 3
MEAN = -4.8 DEGREES
RMS = 6.2 DEGREES
MIN = -23.8 DEGREES
MAX = 12.9 DEGREES
+90% = .4 DEGREES
-90% = -7.9 DEGREES
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00
DEGREES

Figure B-3



CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 4
MEAN = -4.1 DEGREES
RMS = 6.6 DEGREES
MIN = -23.6 DEGREES
MAX = 18.3 DEGREES
+90% = 2.9 DEGREES
-90% = -8.9 DEGREES
% OCCURENCES
DEGREES

Figure B-4

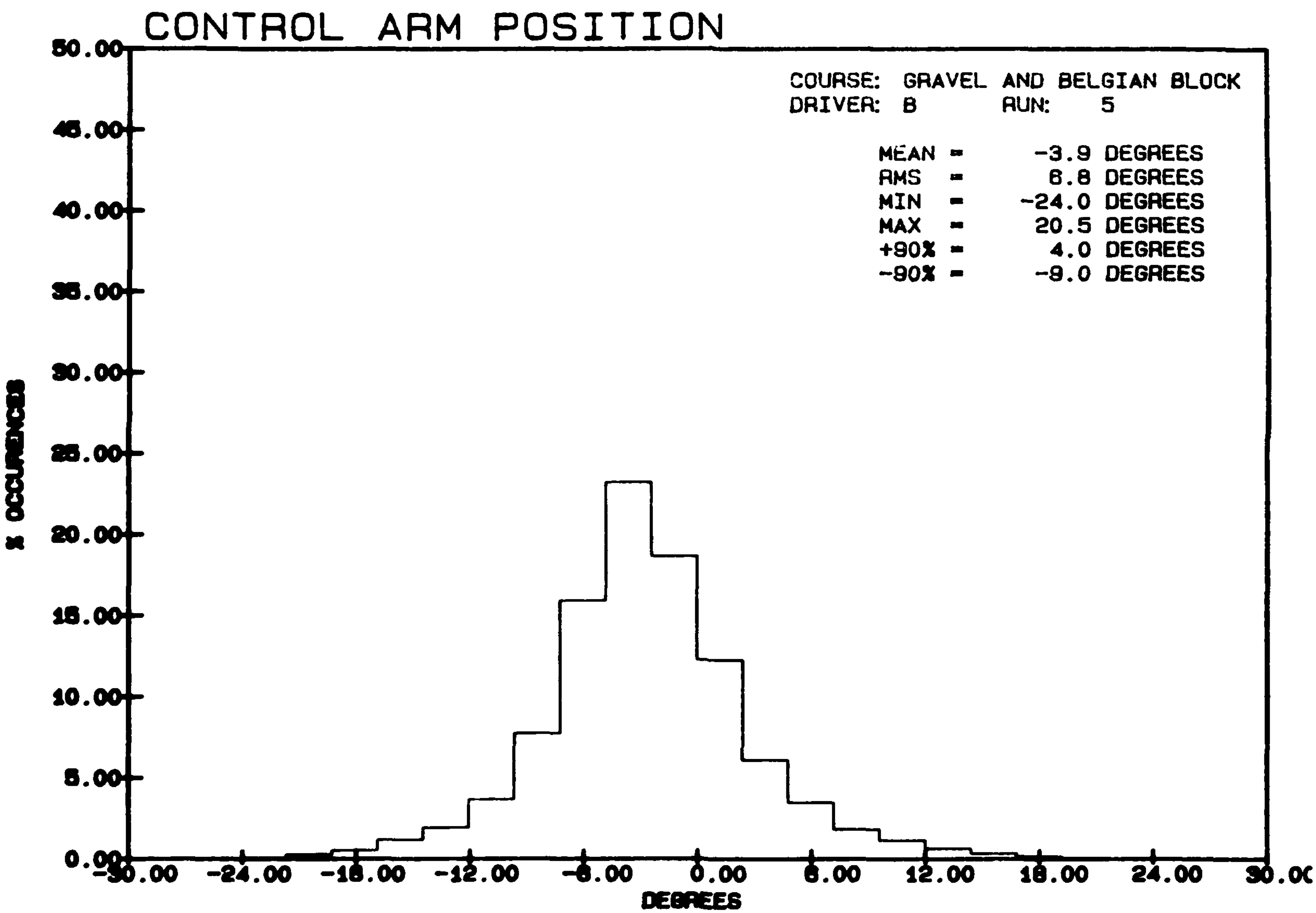

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 5
MEAN = -3.9 DEGREES
RMS = 6.8 DEGREES
MIN = -24.0 DEGREES
MAX = 20.5 DEGREES
+90% = 4.0 DEGREES
-90% = -9.0 DEGREES
% OCCURENCES
DEGREES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00

Figure B-5

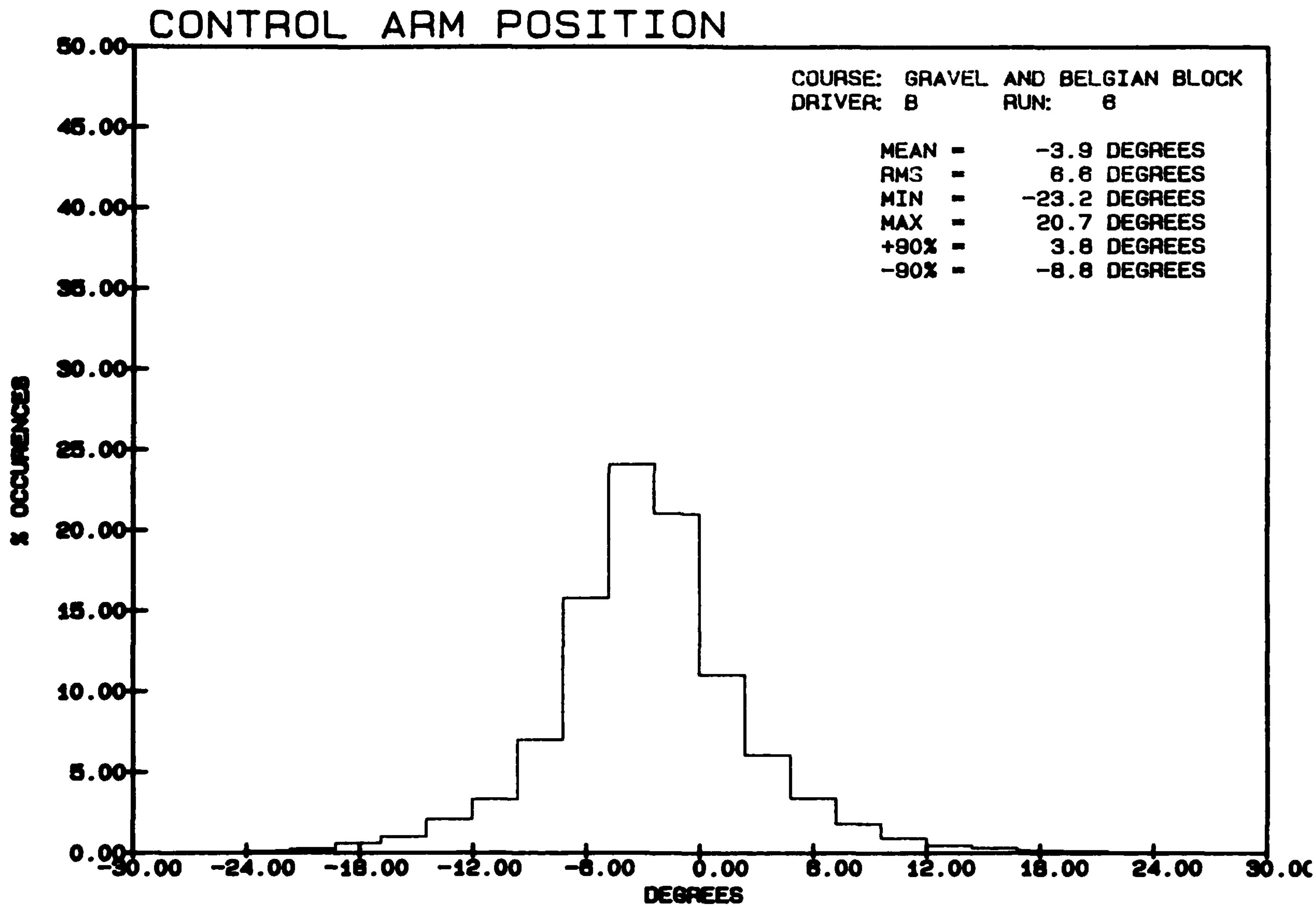

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 6
MEAN = -3.9 DEGREES
RMS = 6.6 DEGREES
MIN = -23.2 DEGREES
MAX = 20.7 DEGREES
+90% = 3.8 DEGREES
-90% = -8.8 DEGREES
% OCCURENCES
DEGREES
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00

Figure B-6

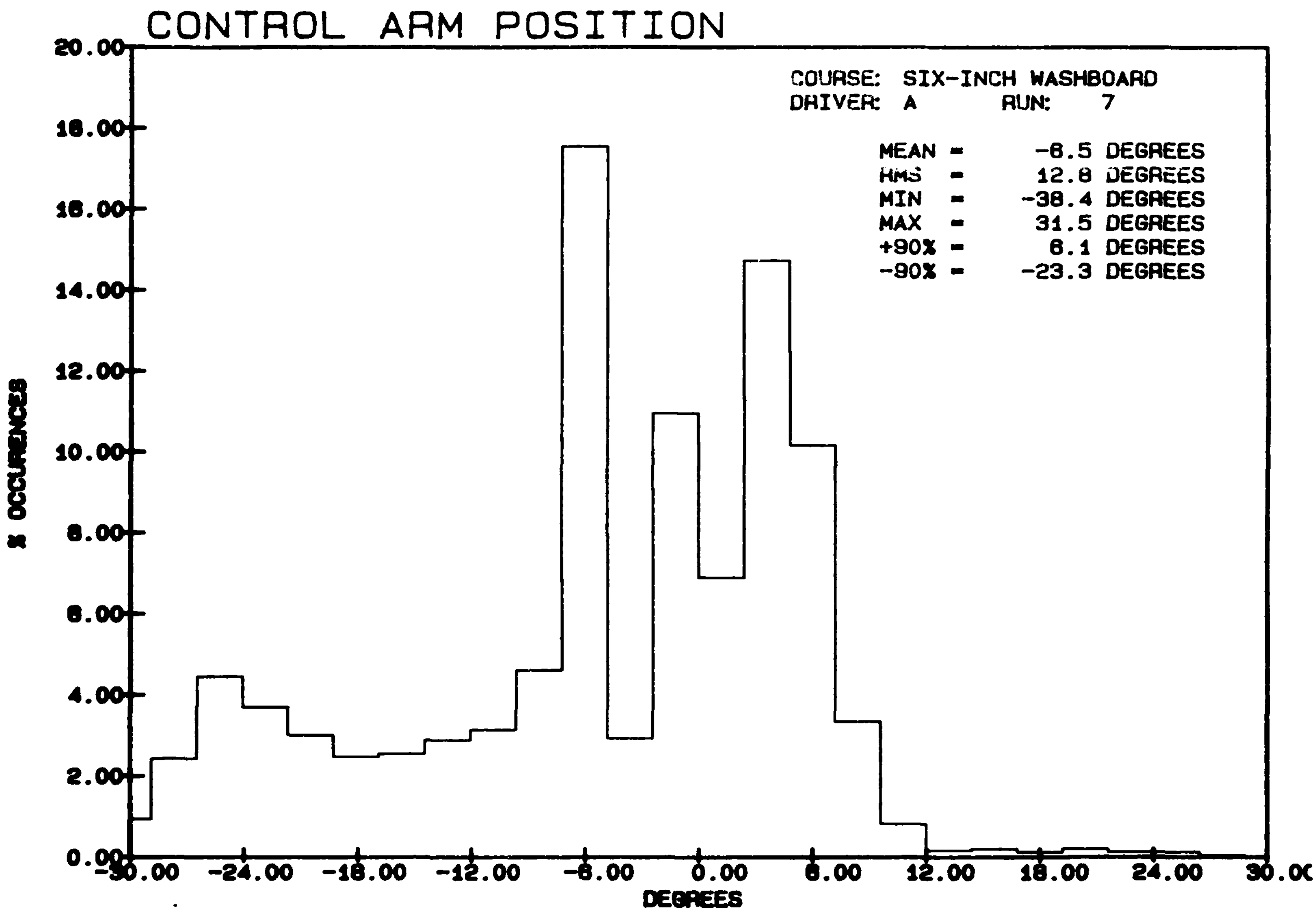

CONTROL ARM POSITION
COURSE: SIX-INCH WASHBOARD
DRIVER: A RUN: 7
MEAN = -6.5 DEGREES
RMS = 12.8 DEGREES
MIN = -38.4 DEGREES
MAX = 31.5 DEGREES
+90% = 6.1 DEGREES
-90% = -23.3 DEGREES
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00
DEGREES

Figure B-7

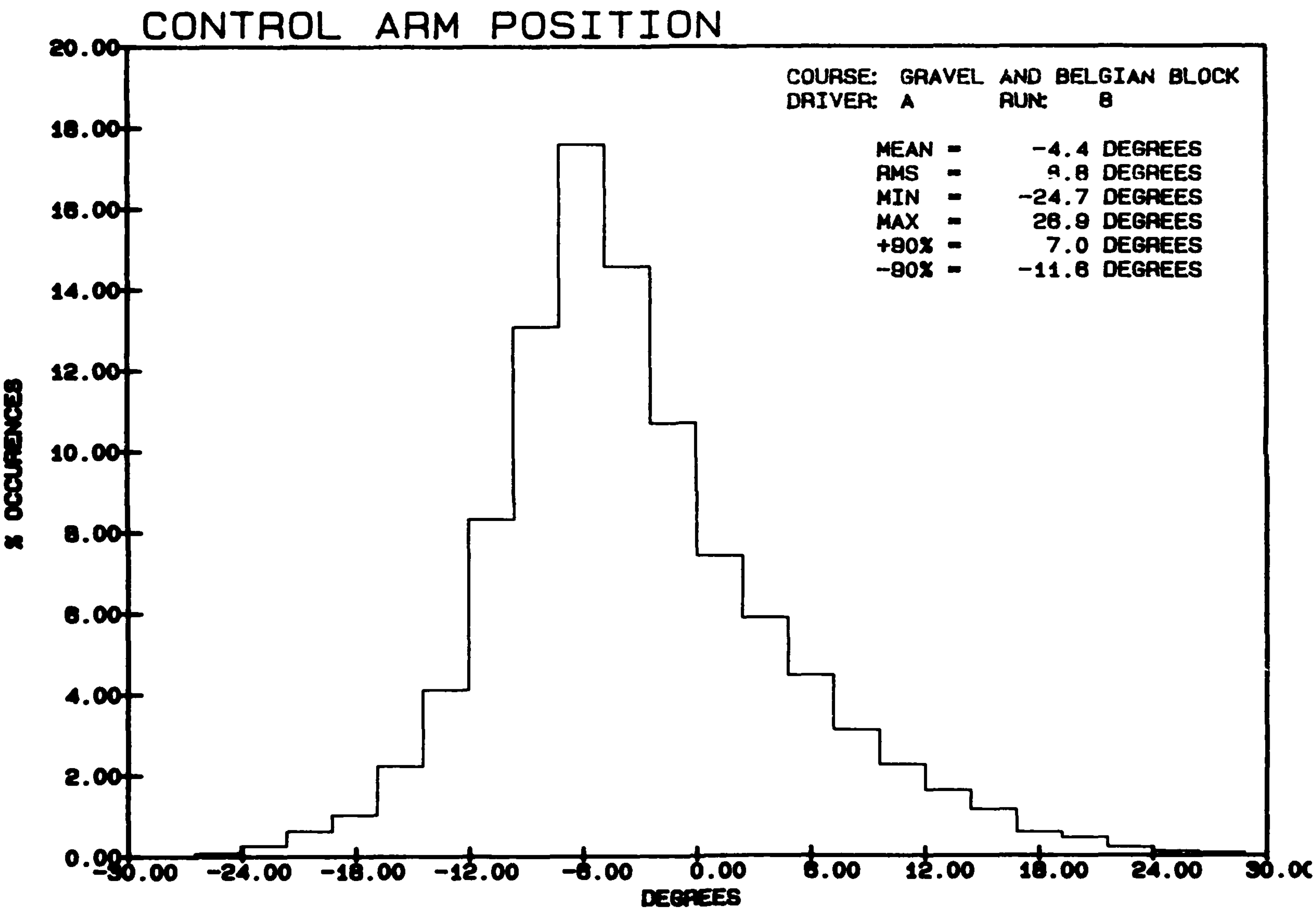

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 8
MEAN = -4.4 DEGREES
RMS = 9.8 DEGREES
MIN = -24.7 DEGREES
MAX = 28.9 DEGREES
+90% = 7.0 DEGREES
-90% = -11.6 DEGREES
% OCCURENCES
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00
DEGREES

Figure B-8

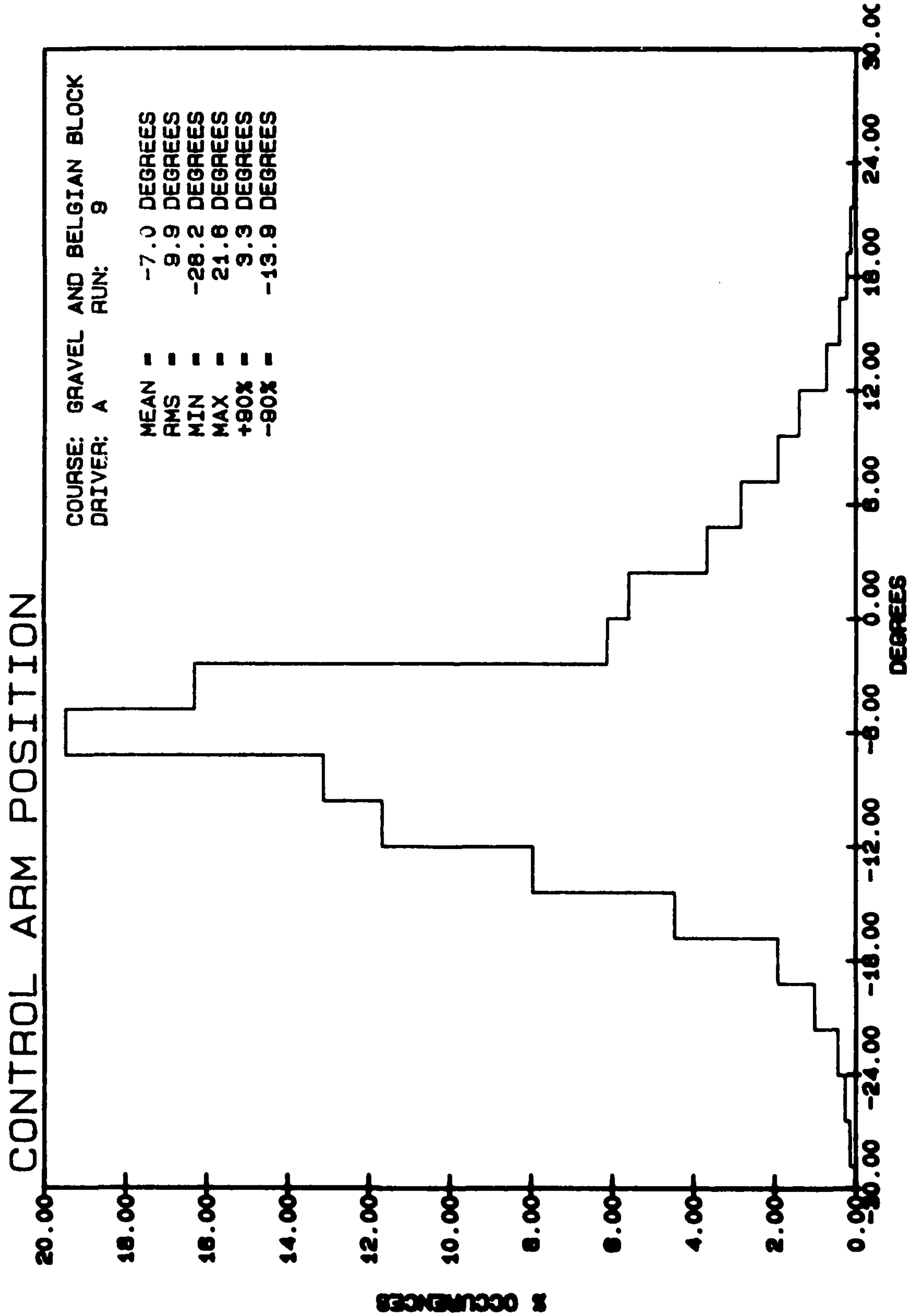

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 9
MEAN = -7.0 DEGREES
RMS = 9.9 DEGREES
MIN = -28.2 DEGREES
MAX = 21.6 DEGREES
+90% = 9.3 DEGREES
-90% = -13.9 DEGREES
% OCCURENCES
DEGREES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00

Figure B-9

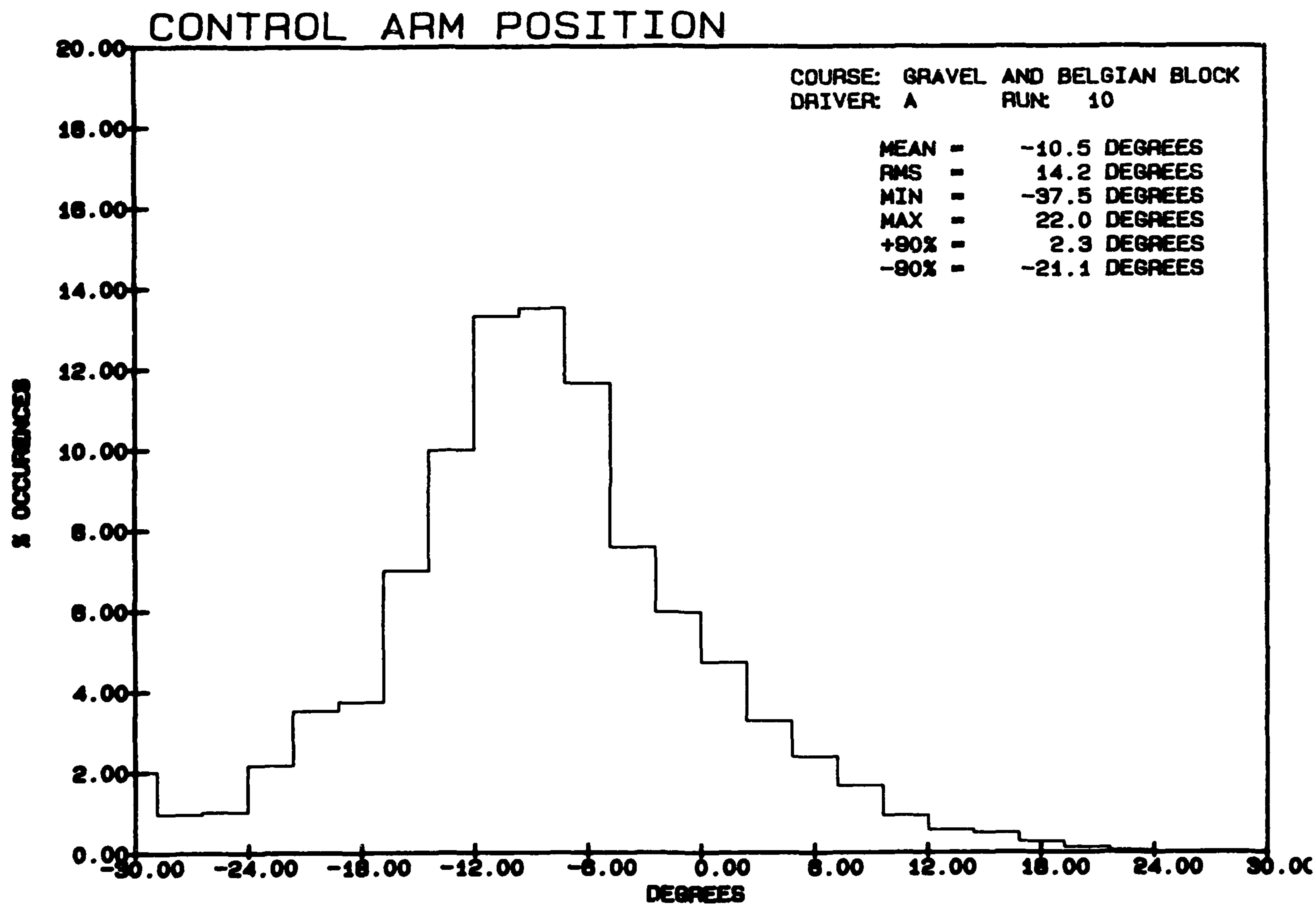

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 10
MEAN = -10.5 DEGREES
RMS = 14.2 DEGREES
MIN = -37.5 DEGREES
MAX = 22.0 DEGREES
+90% = 2.3 DEGREES
-90% = -21.1 DEGREES
% OCCURENCES
DEGREES
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00

Figure B-10

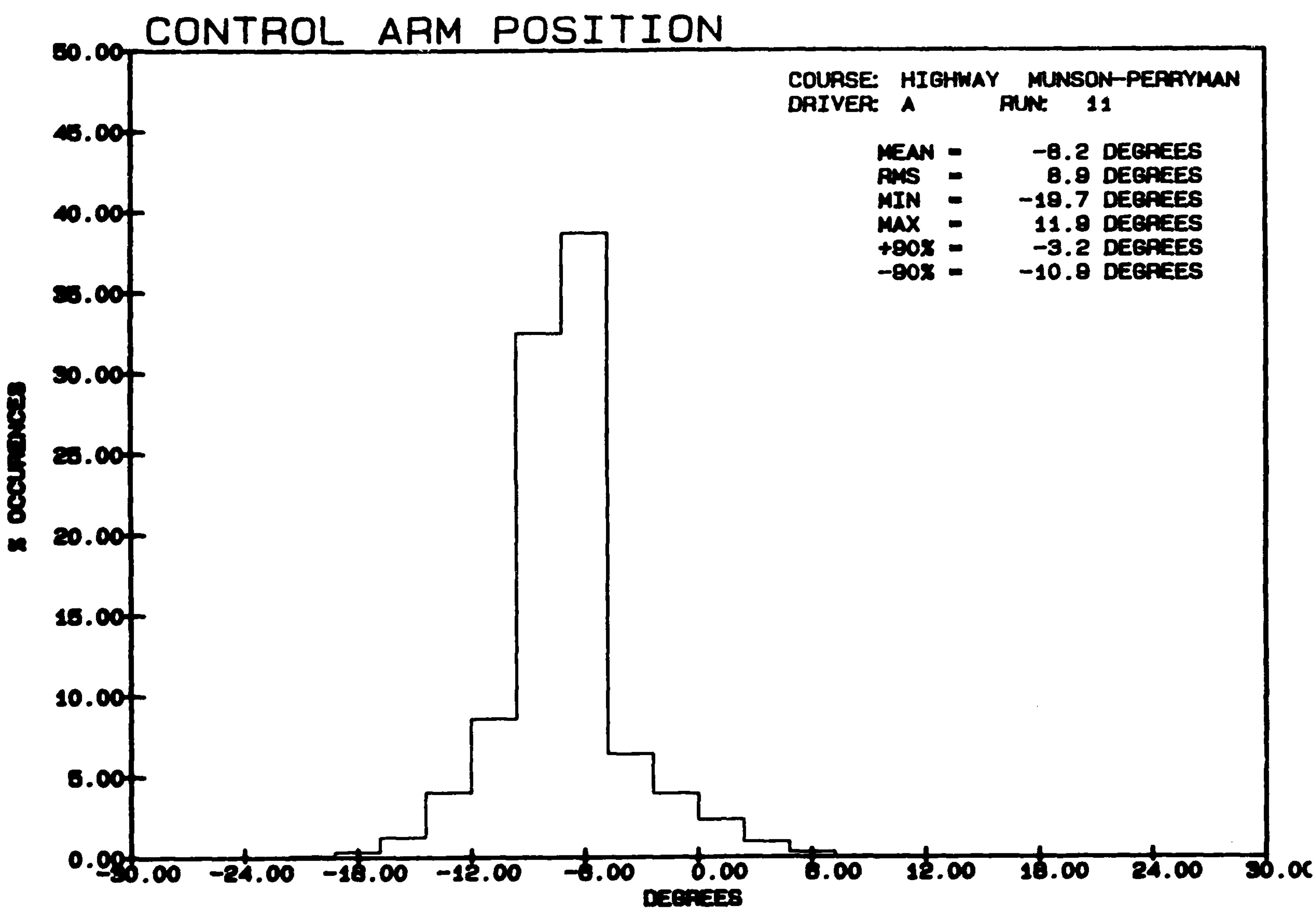

CONTROL ARM POSITION
COURSE: HIGHWAY MUNSON-PERRYMAN
DRIVER: A RUN: 11
MEAN = -8.2 DEGREES
RMS = 8.9 DEGREES
MIN = -19.7 DEGREES
MAX = 11.9 DEGREES
+90% = -3.2 DEGREES
-90% = -10.9 DEGREES
% OCCURRENCES
DEGREES
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00

Figure B-11

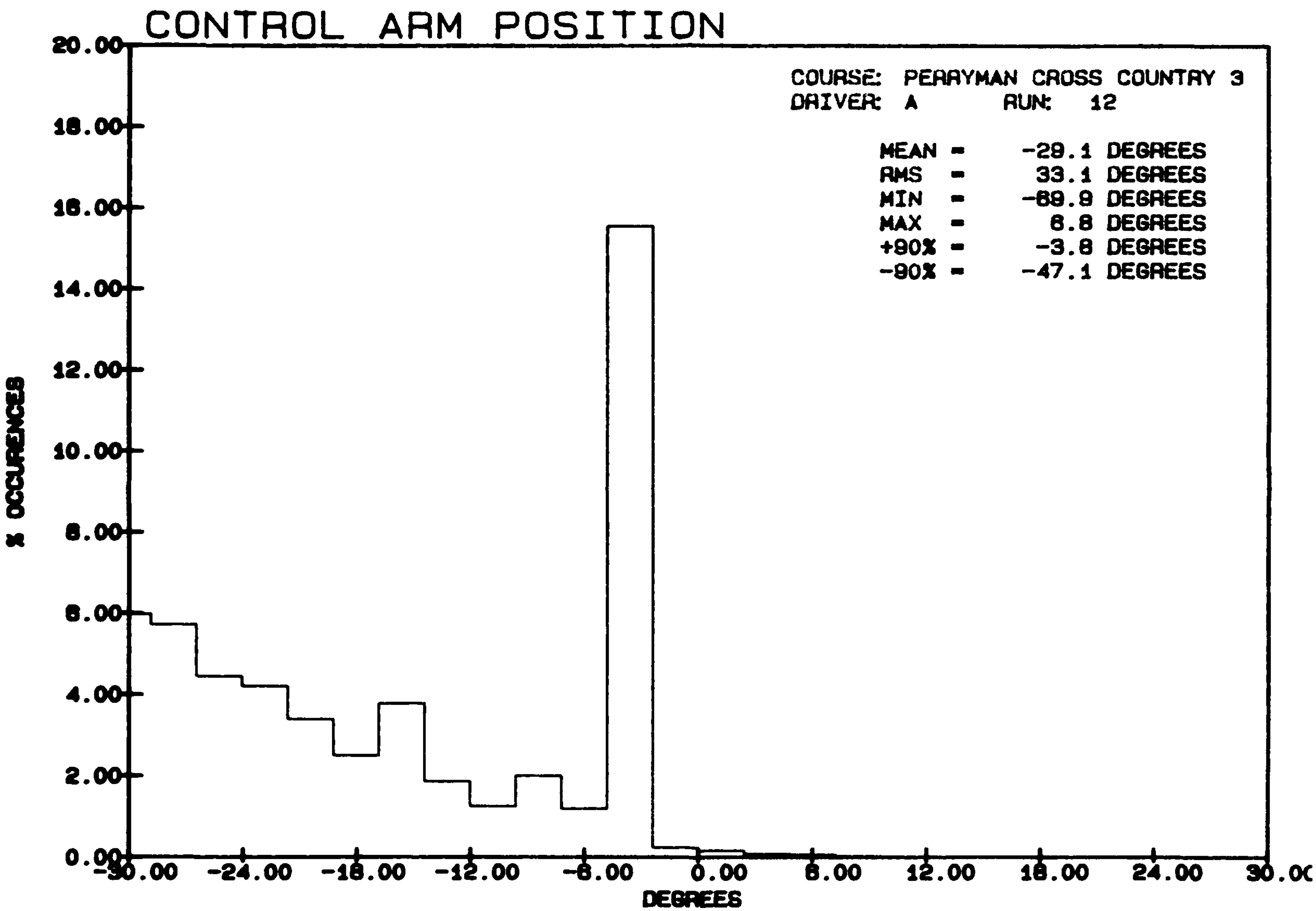

CONTROL ARM POSITION
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 12
MEAN = -29.1 DEGREES
RMS = 33.1 DEGREES
MIN = -69.9 DEGREES
MAX = 6.8 DEGREES
+90% = -3.8 DEGREES
-90% = -47.1 DEGREES
% OCCURENCES
DEGREES
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00

Figure B-12

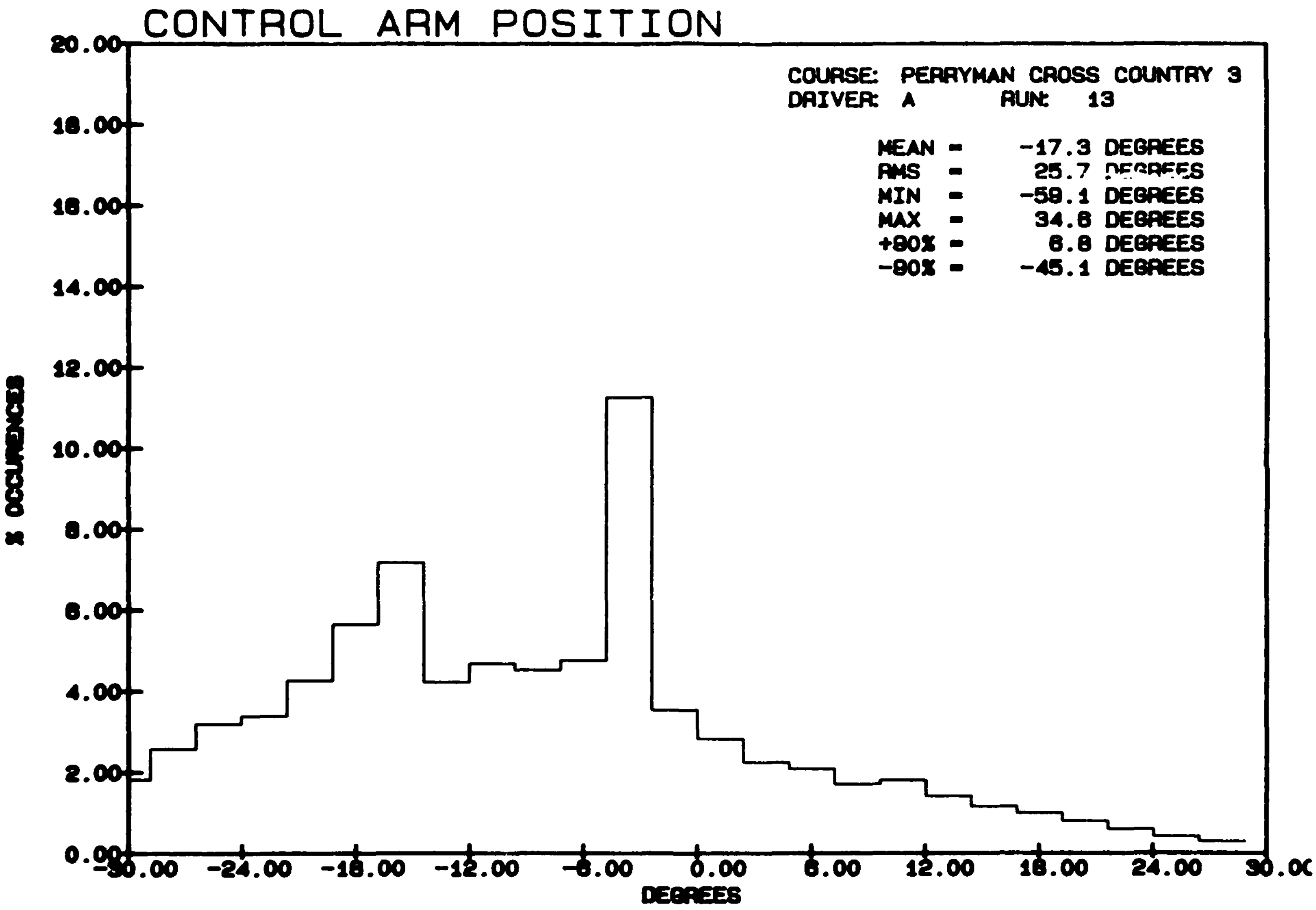

CONTROL ARM POSITION
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 13
MEAN = -17.3 DEGREES
RMS = 25.7 DEGREES
MIN = -59.1 DEGREES
MAX = 34.8 DEGREES
+90% = 6.8 DEGREES
-90% = -45.1 DEGREES
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00
DEGREES

Figure B-13

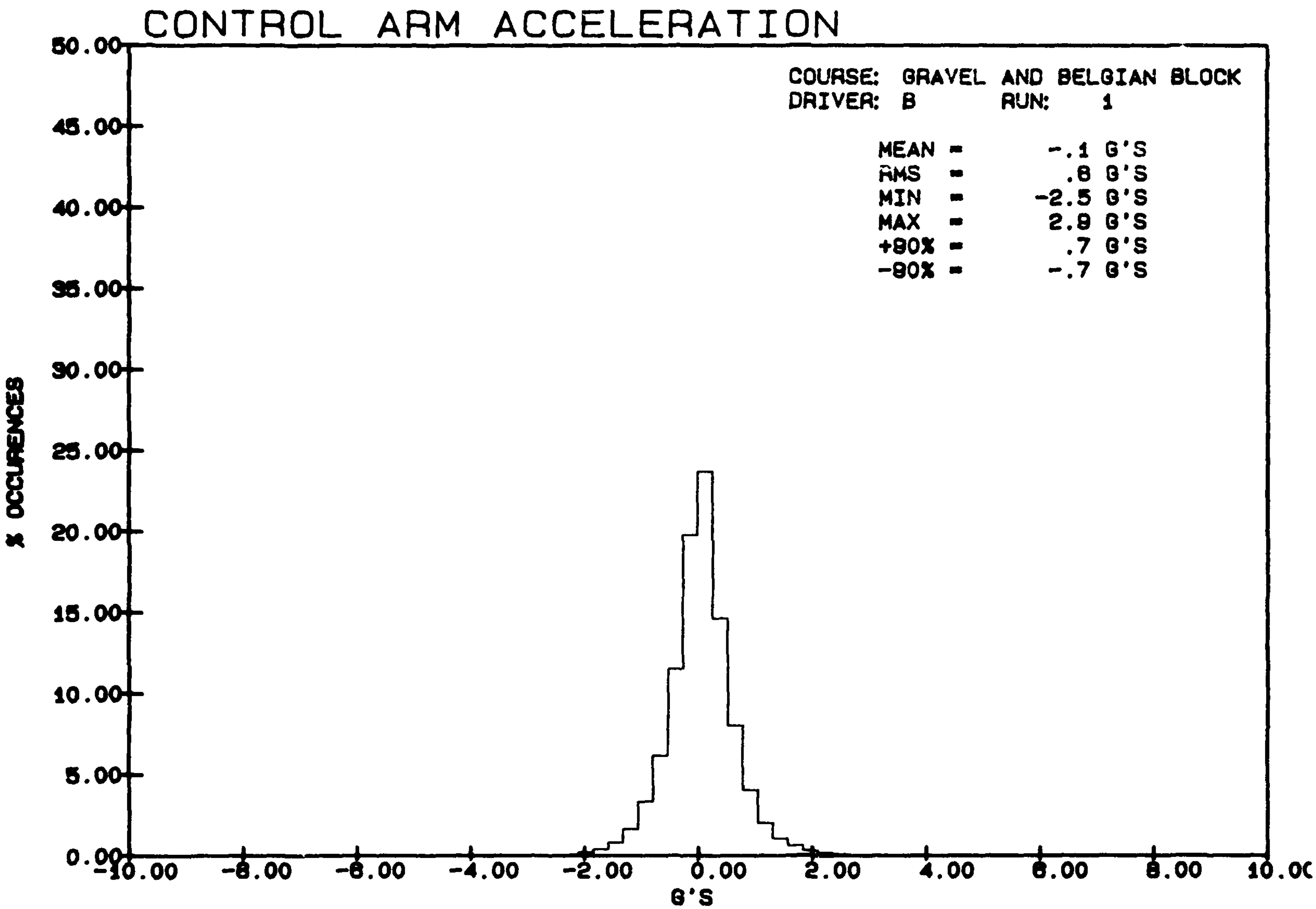
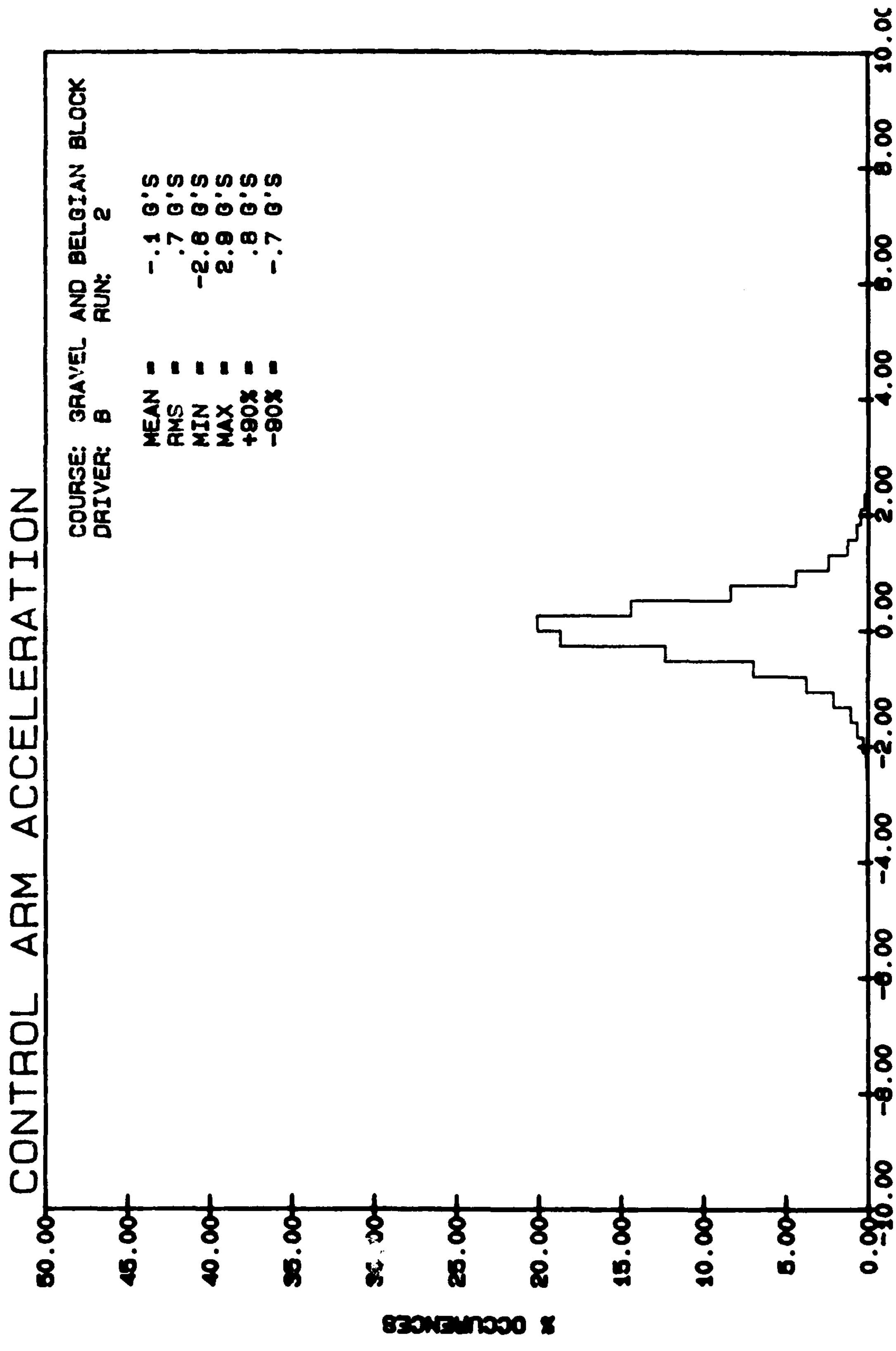

CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 1
MEAN = -.1 G'S
RMS = .8 G'S
MIN = -2.5 G'S
MAX = 2.9 G'S
+90% = .7 G'S
-90% = -.7 G'S
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
G'S

Figure B-14



CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B
RUN: 2
MEAN = -.1 G'S
RMS = .7 G'S
MIN = -2.8 G'S
MAX = 2.9 G'S
+90% = .8 G'S
-90% = -.7 G'S
% OCCURRENCES
G'S
0.00
5.00
10.00
15.00
20.00
25.00
35.00
40.00
45.00
50.00
-10.00
-8.00
-6.00
-4.00
-2.00
2.00
4.00
6.00
8.00

Figure B-15

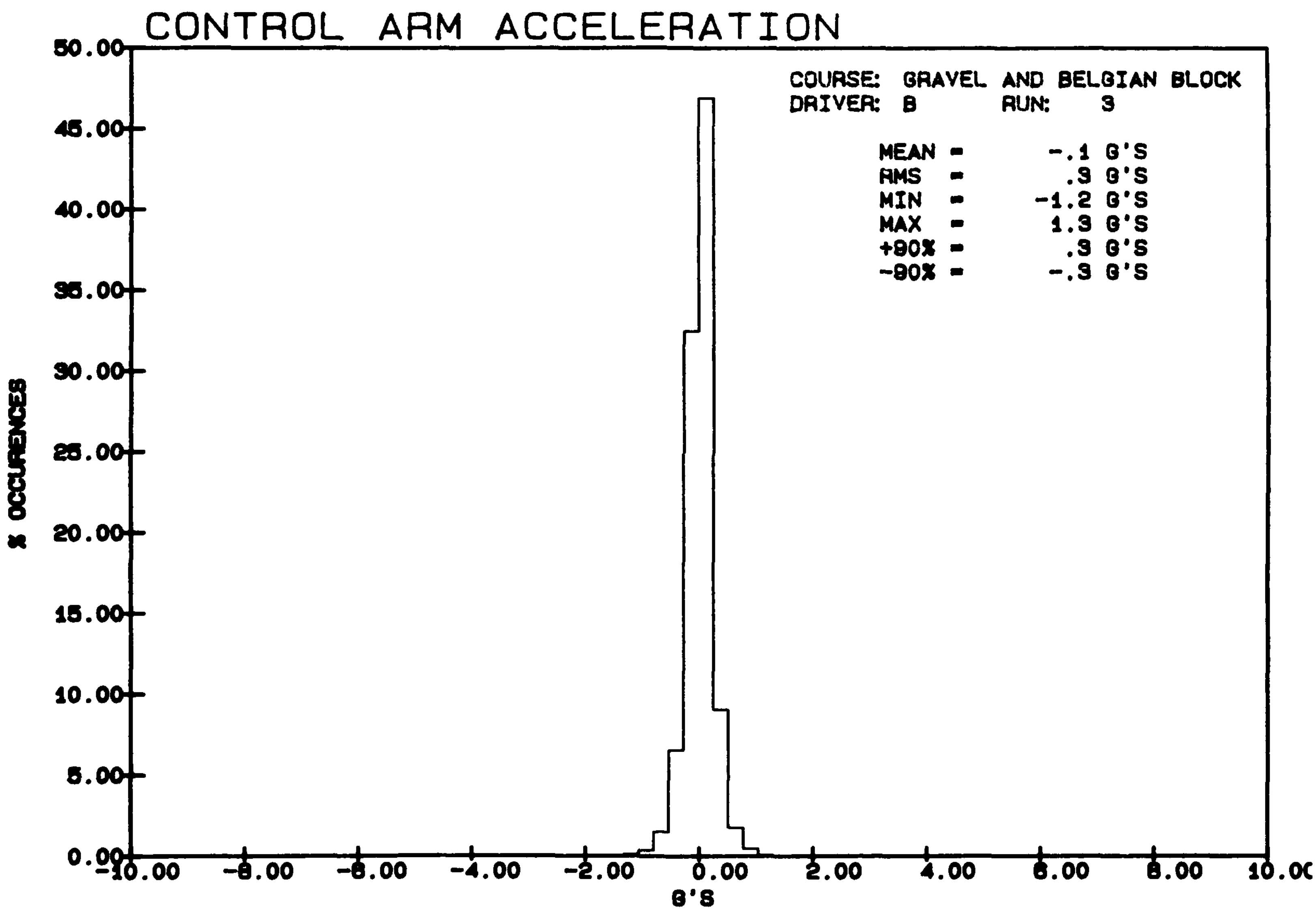

CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 3
MEAN = -.1 G'S
RMS = .3 G'S
MIN = -1.2 G'S
MAX = 1.3 G'S
+90% = .3 G'S
-90% = -.3 G'S
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
G'S

Figure B-16

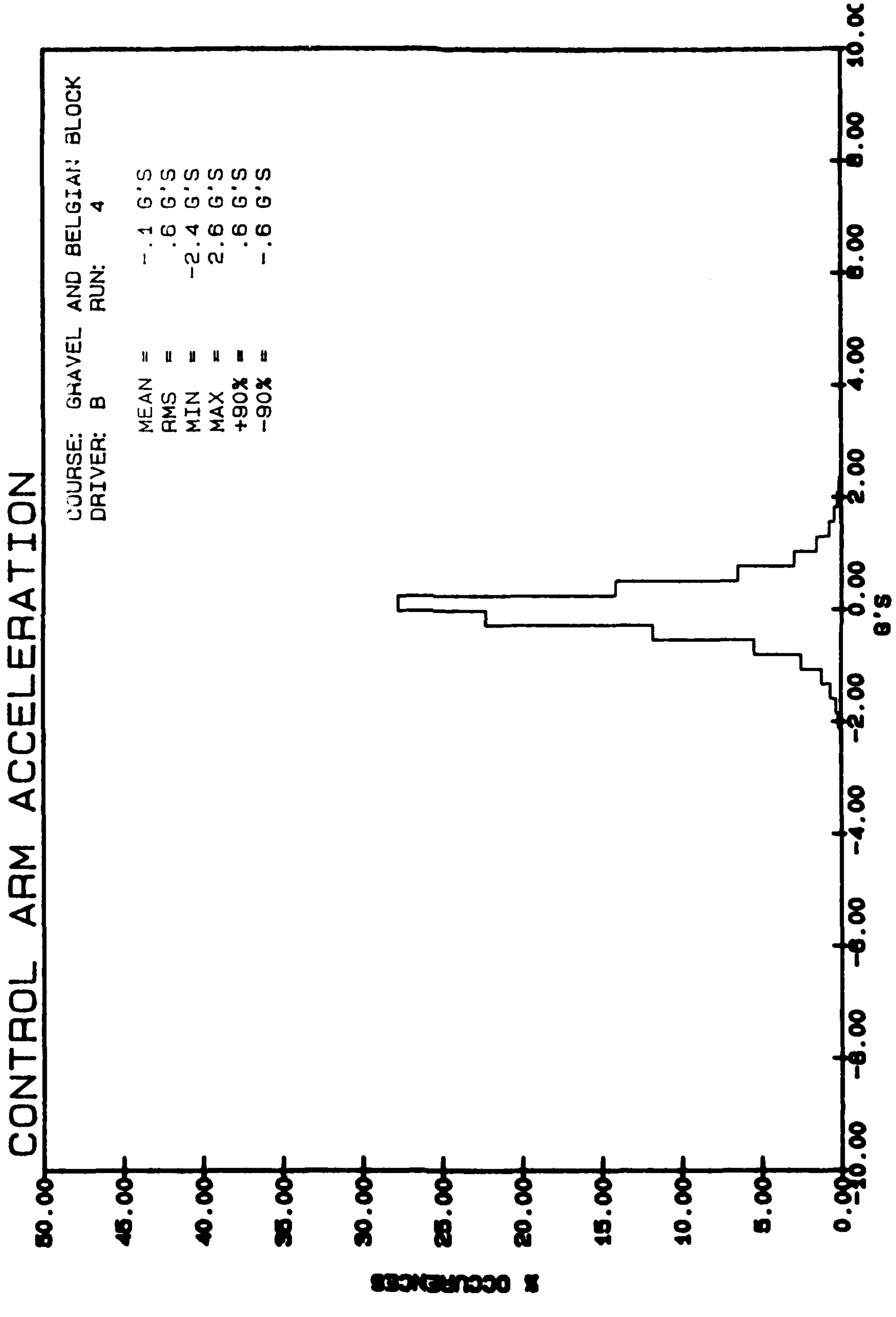

CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 4
MEAN = -.1 G'S
RMS = .6 G'S
MIN = -2.4 G'S
MAX = 2.6 G'S
+90% = .6 G'S
-90% = -.6 G'S
% OCCURENCES
G'S
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00

Figure B-17

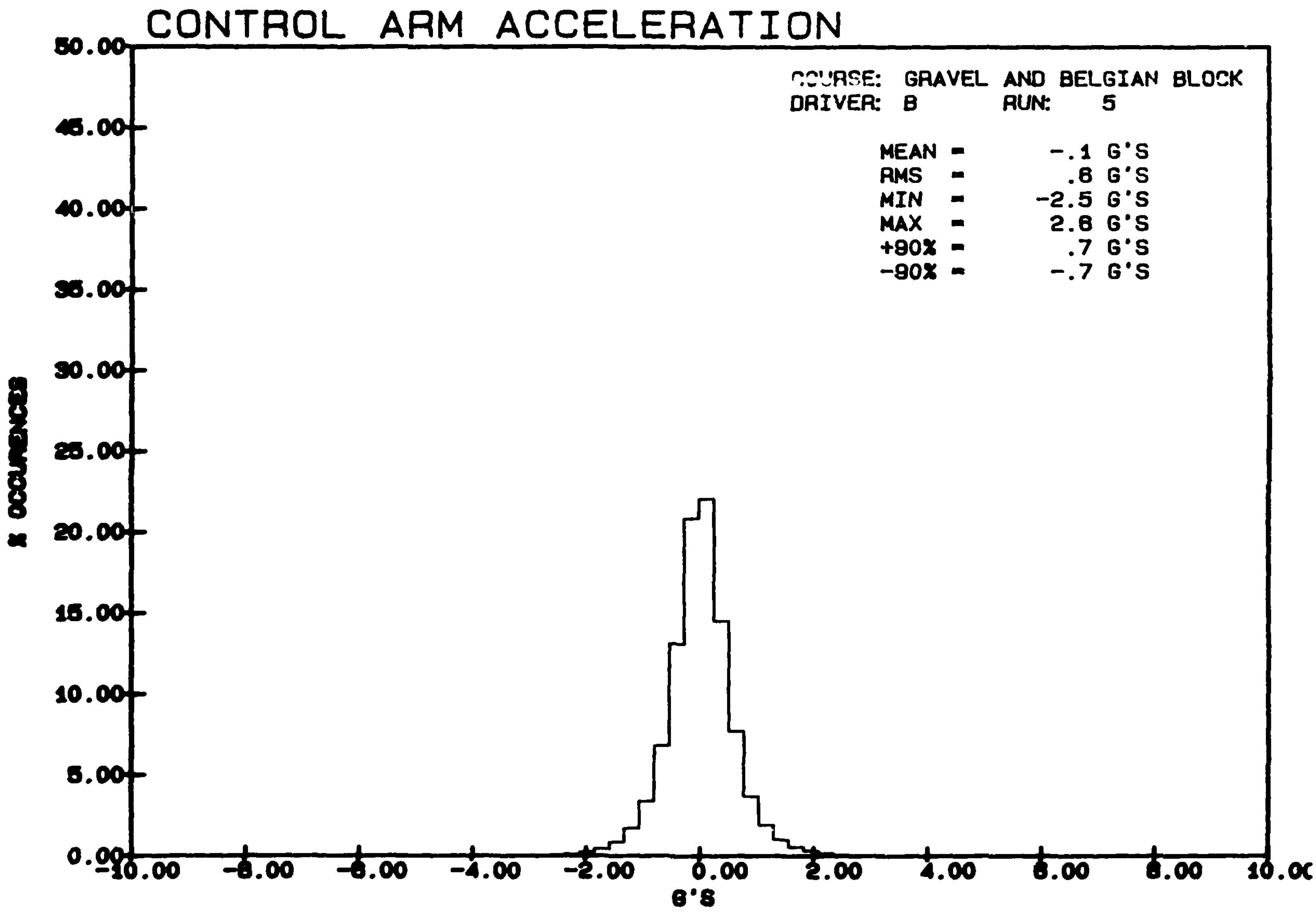

CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 5
MEAN = -.1 G'S
RMS = .8 G'S
MIN = -2.5 G'S
MAX = 2.8 G'S
+90% = .7 G'S
-90% = -.7 G'S
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
G'S

Figure B-18

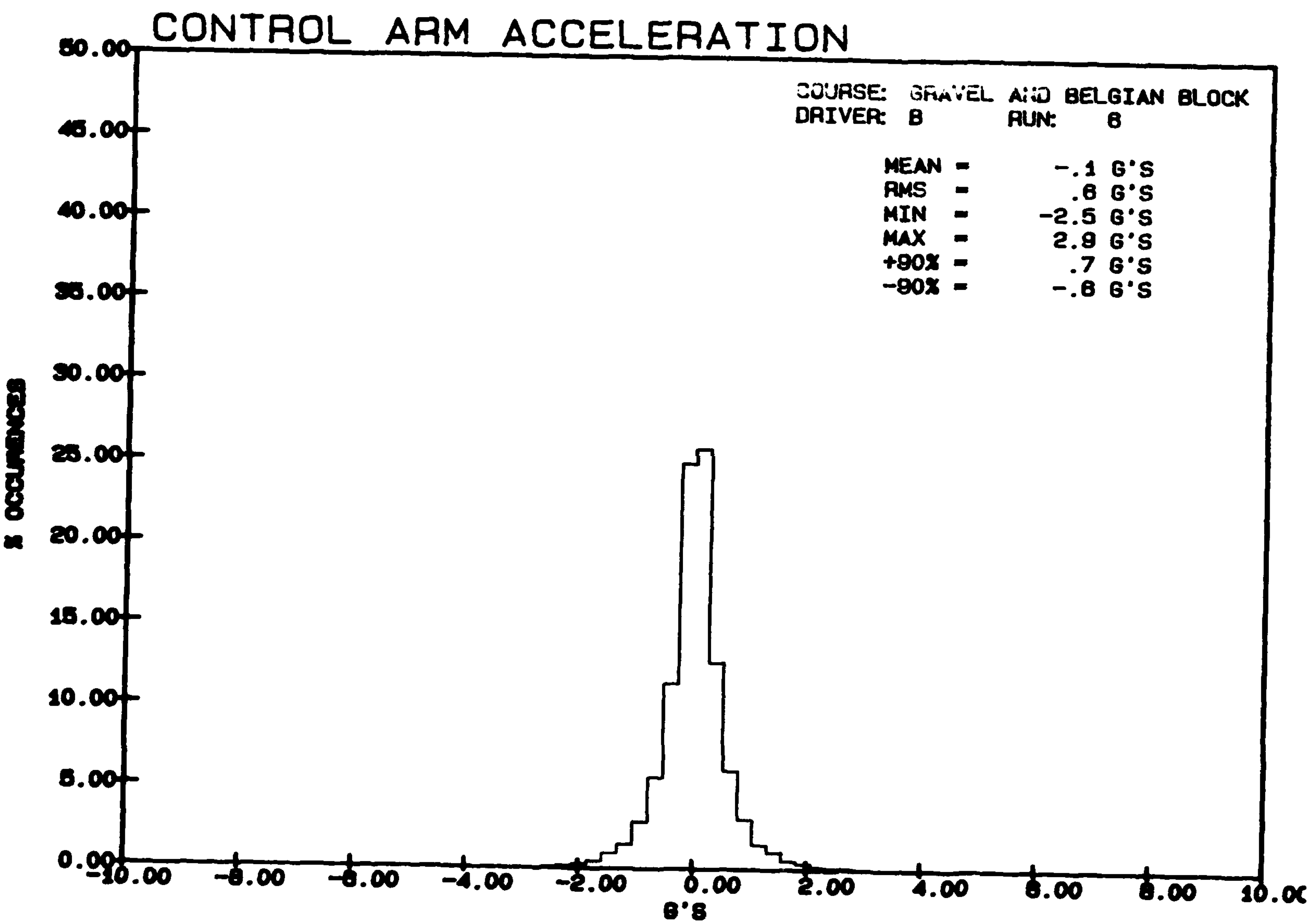

CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 6
MEAN = -.1 G'S
RMS = .6 G'S
MIN = -2.5 G'S
MAX = 2.9 G'S
+90% = .7 G'S
-90% = -.6 G'S
% OCCURRENCES
G'S

Figure B-19

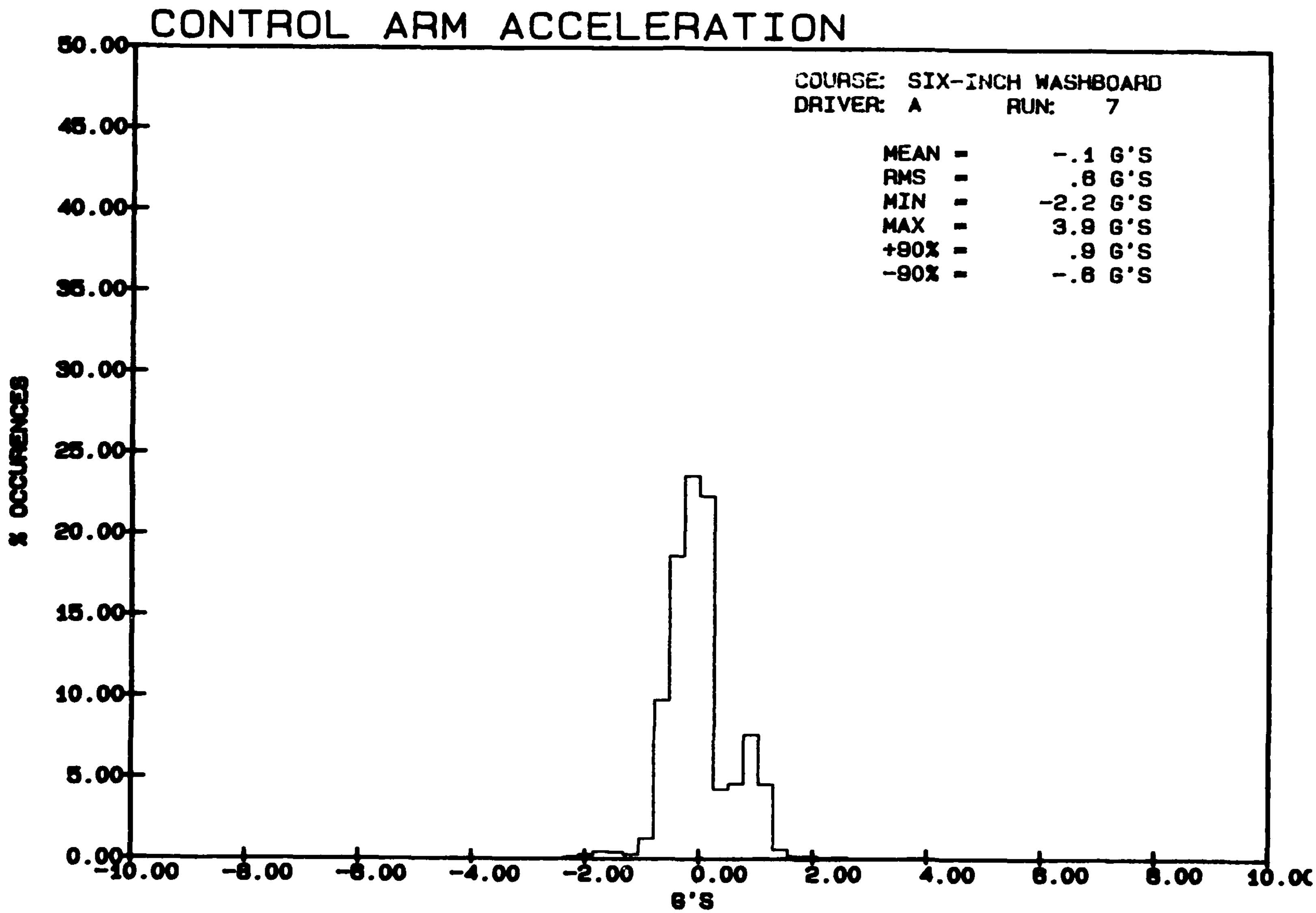

CONTROL ARM ACCELERATION
COURSE: SIX-INCH WASHBOARD
DRIVER: A RUN: 7
MEAN = -.1 G'S
RMS = .6 G'S
MIN = -2.2 G'S
MAX = 3.9 G'S
+90% = .9 G'S
-90% = -.6 G'S
% OCCURENCES
G'S
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00

Figure B-20

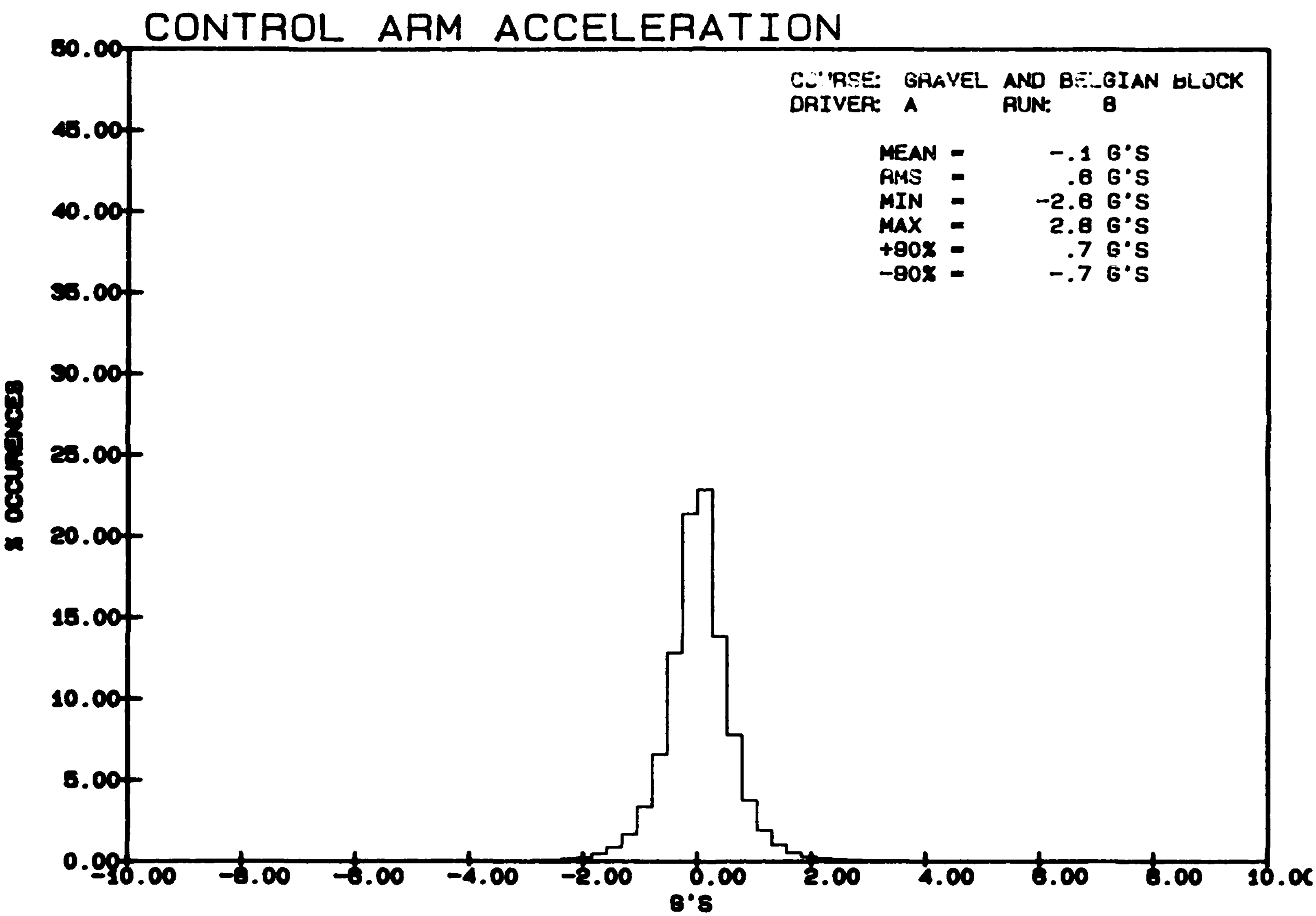
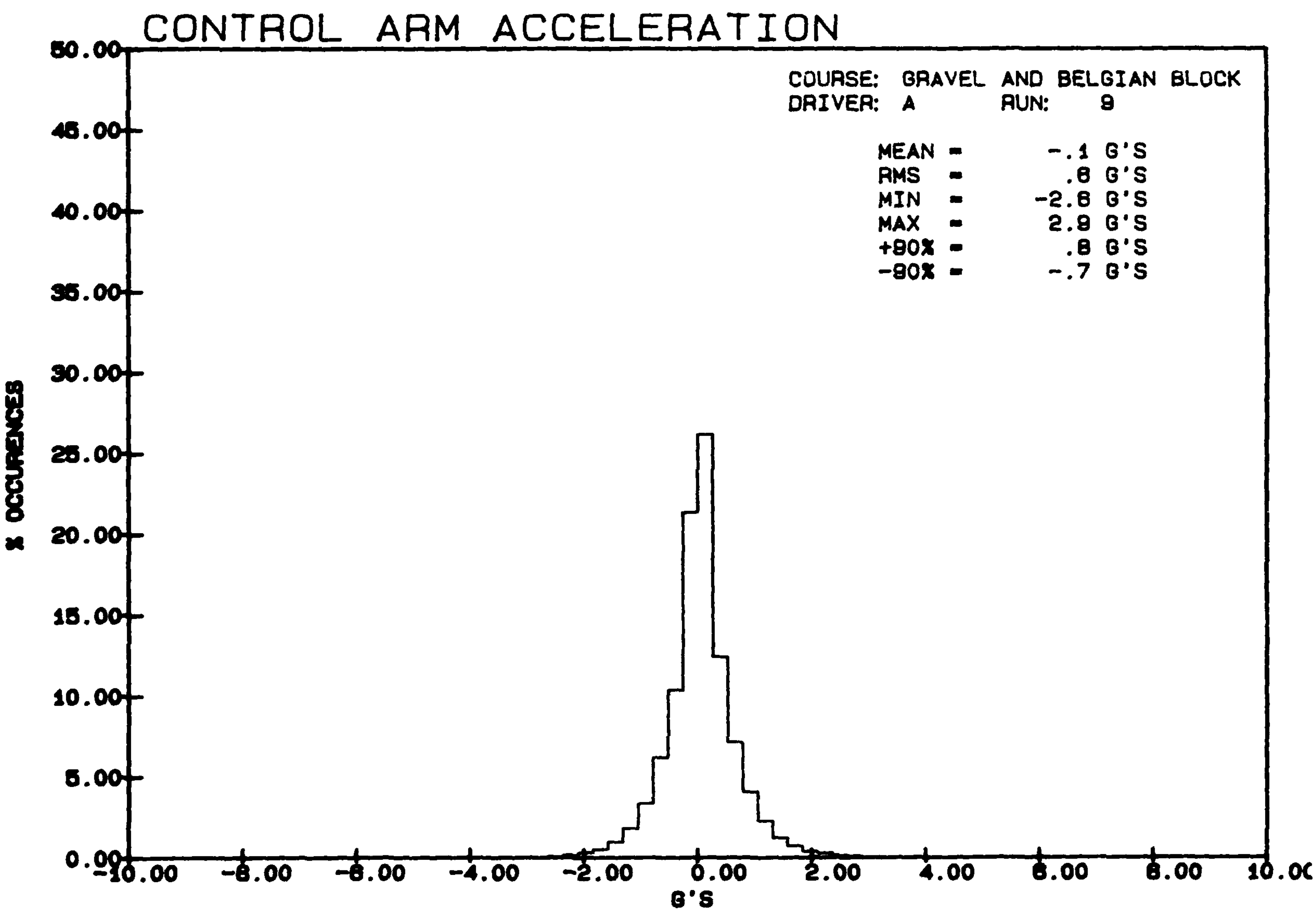

CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 8
MEAN = -.1 G'S
RMS = .6 G'S
MIN = -2.6 G'S
MAX = 2.8 G'S
+90% = .7 G'S
-90% = -.7 G'S
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
G'S

Figure B-21



CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 9
MEAN = -.1 G'S
RMS = .8 G'S
MIN = -2.6 G'S
MAX = 2.9 G'S
+90% = .8 G'S
-90% = -.7 G'S
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
G'S

Figure B-22

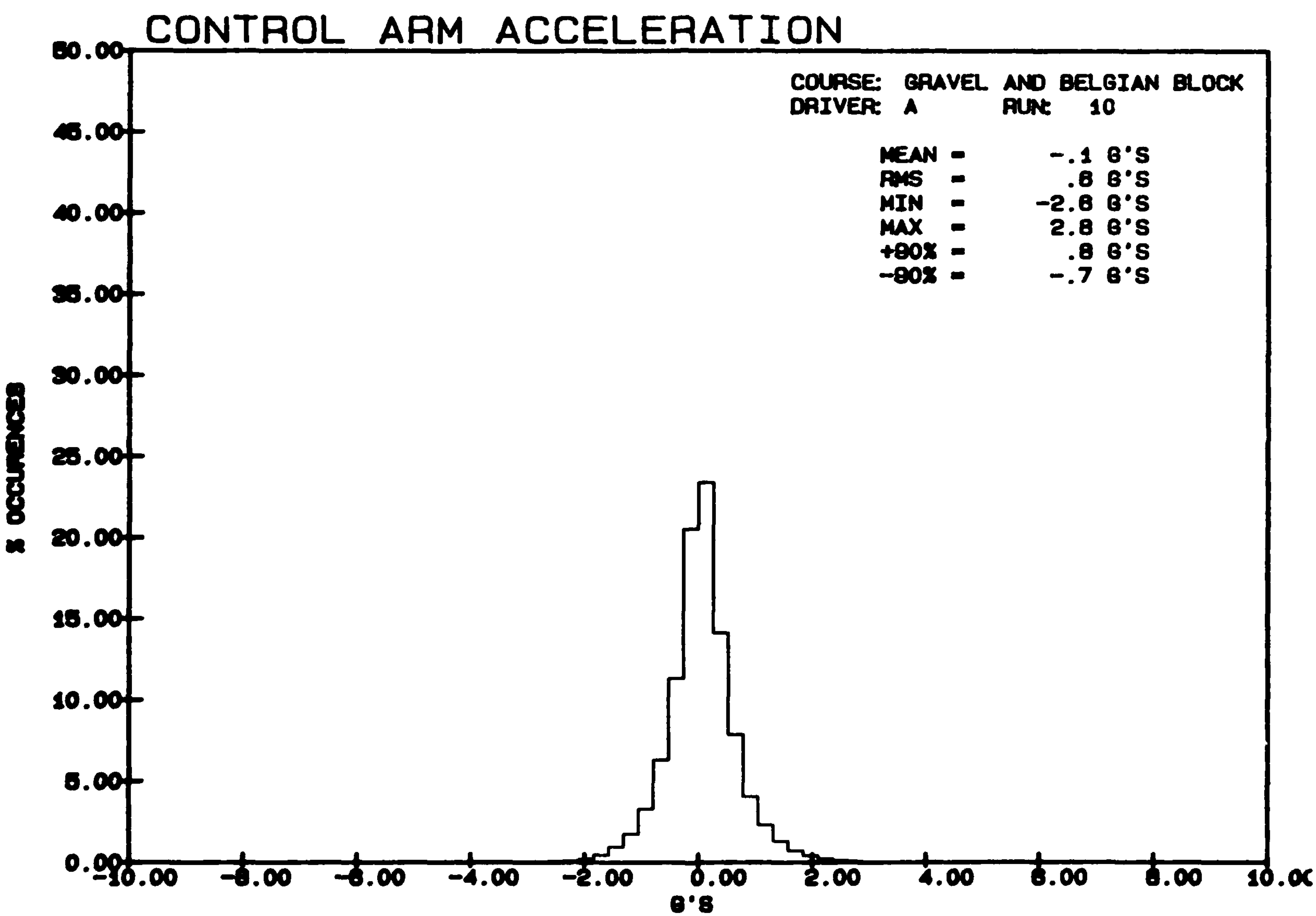

CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 10
MEAN = -.1 G'S
RMS = .6 G'S
MIN = -2.6 G'S
MAX = 2.8 G'S
+90% = .8 G'S
-90% = -.7 G'S
% OCCURRENCES
G'S

Figure B-23

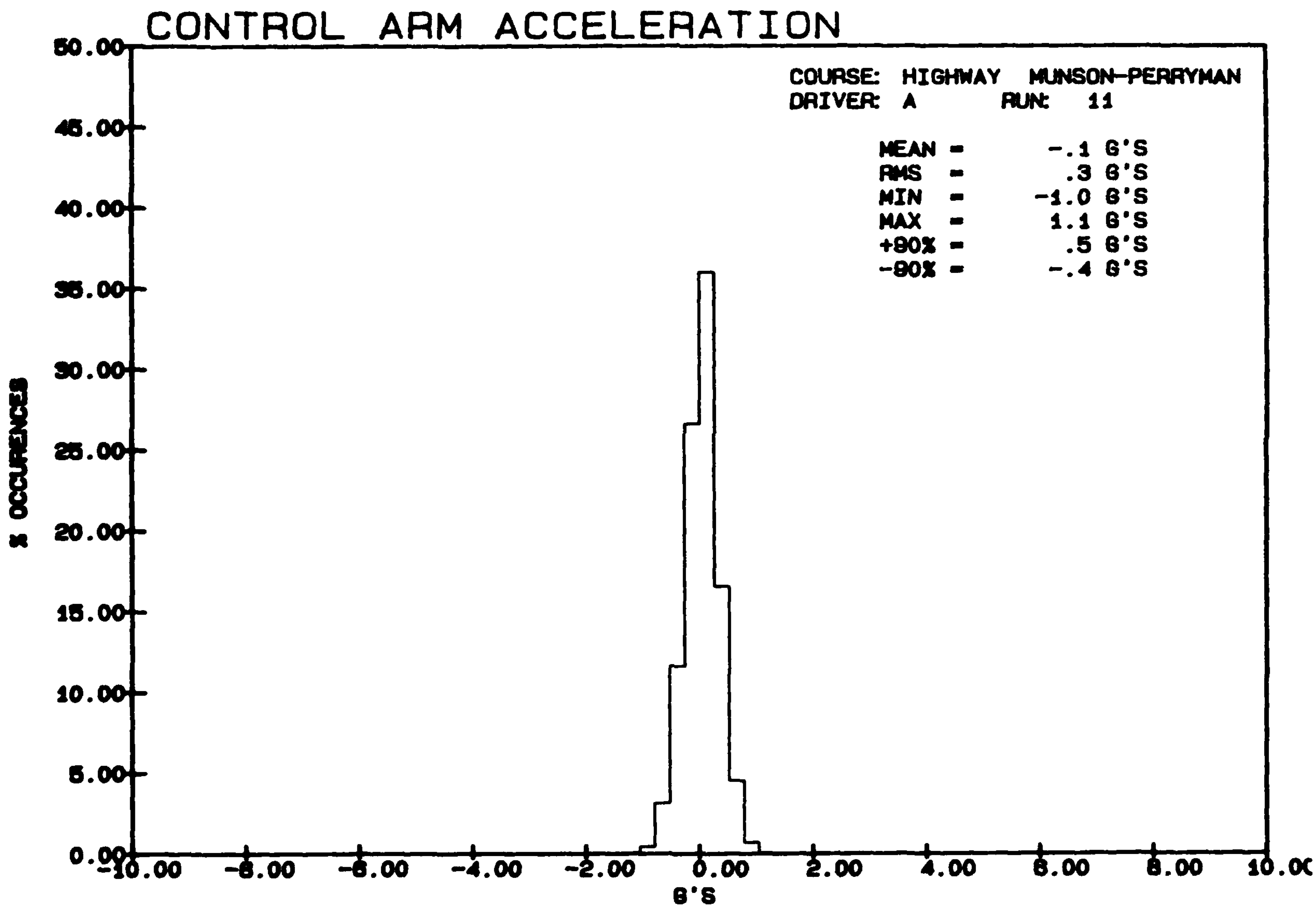

CONTROL ARM ACCELERATION
COURSE: HIGHWAY MUNSON-PERRYMAN
DRIVER: A RUN: 11
MEAN = -.1 G'S
RMS = .3 G'S
MIN = -1.0 G'S
MAX = 1.1 G'S
+90% = .5 G'S
-90% = -.4 G'S
% OCCURENCES
G'S

Figure B-24

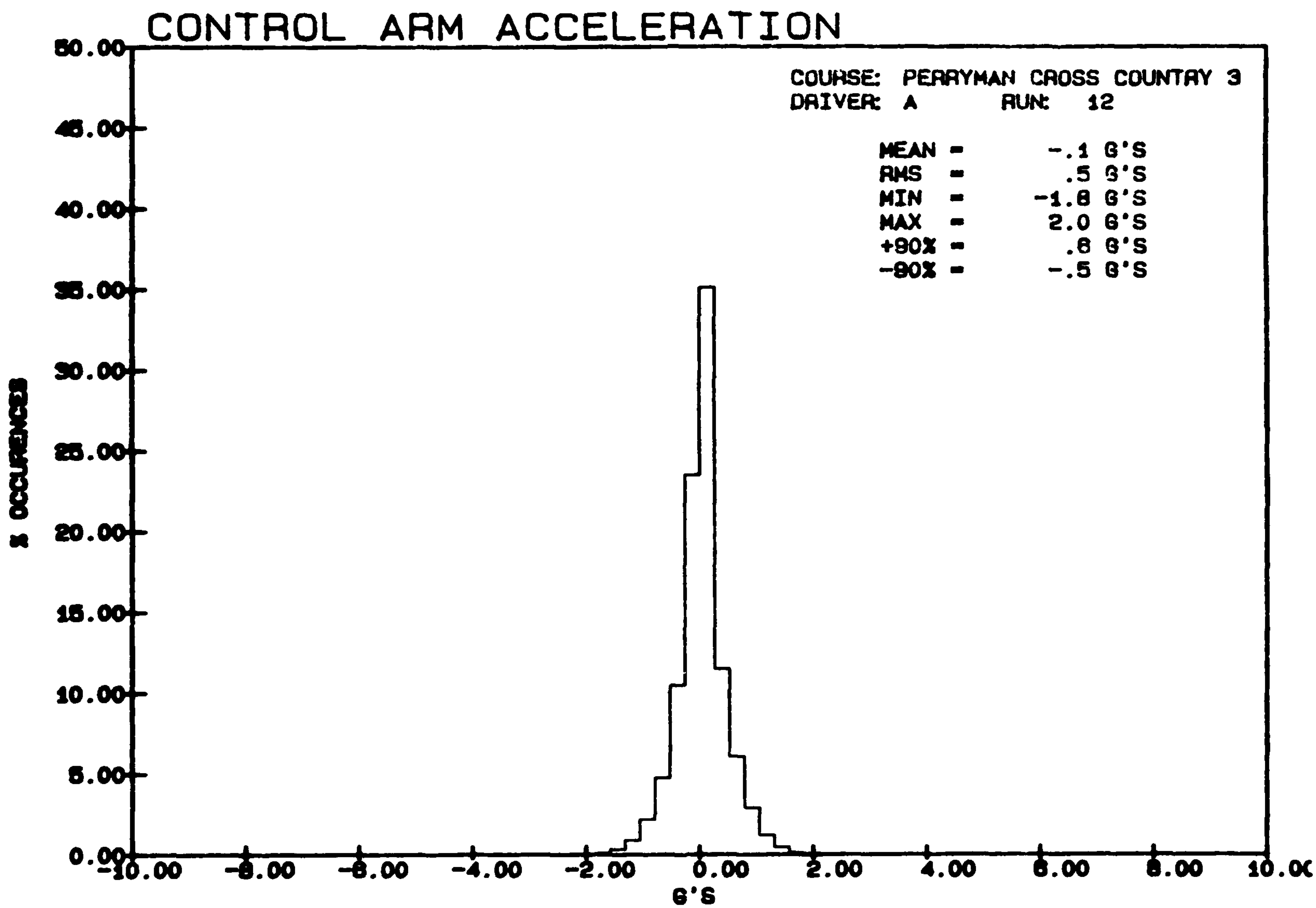

CONTROL ARM ACCELERATION
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 12
MEAN = -.1 G'S
RMS = .5 G'S
MIN = -1.8 G'S
MAX = 2.0 G'S
+90% = .8 G'S
-90% = -.5 G'S
% OCCURENCES
G'S

Figure B-25

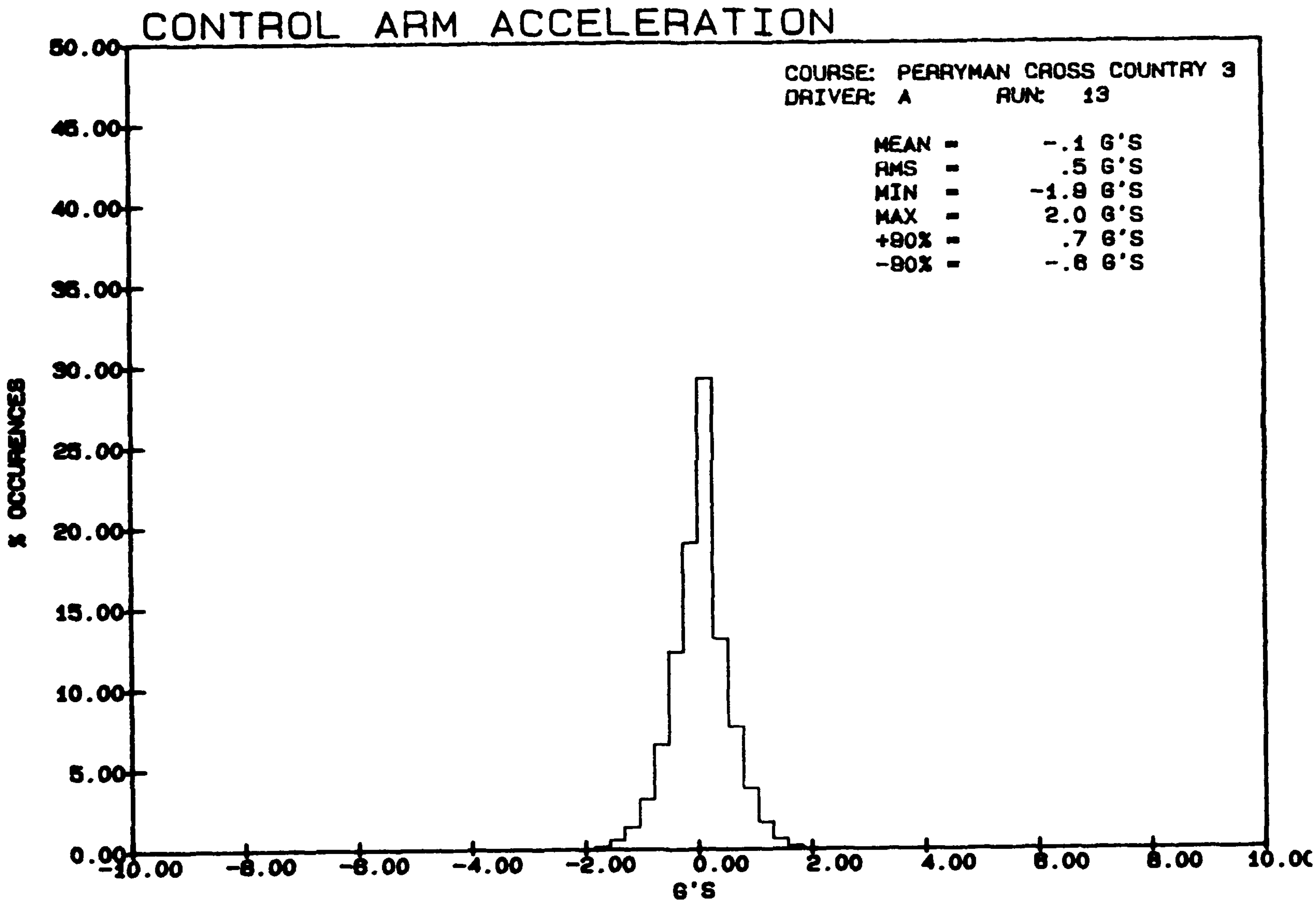

CONTROL ARM ACCELERATION
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 13
MEAN = -.1 G'S
RMS = .5 G'S
MIN = -1.9 G'S
MAX = 2.0 G'S
+90% = .7 G'S
-90% = -.6 G'S
% OCCURENCES
G'S

Figure B-26

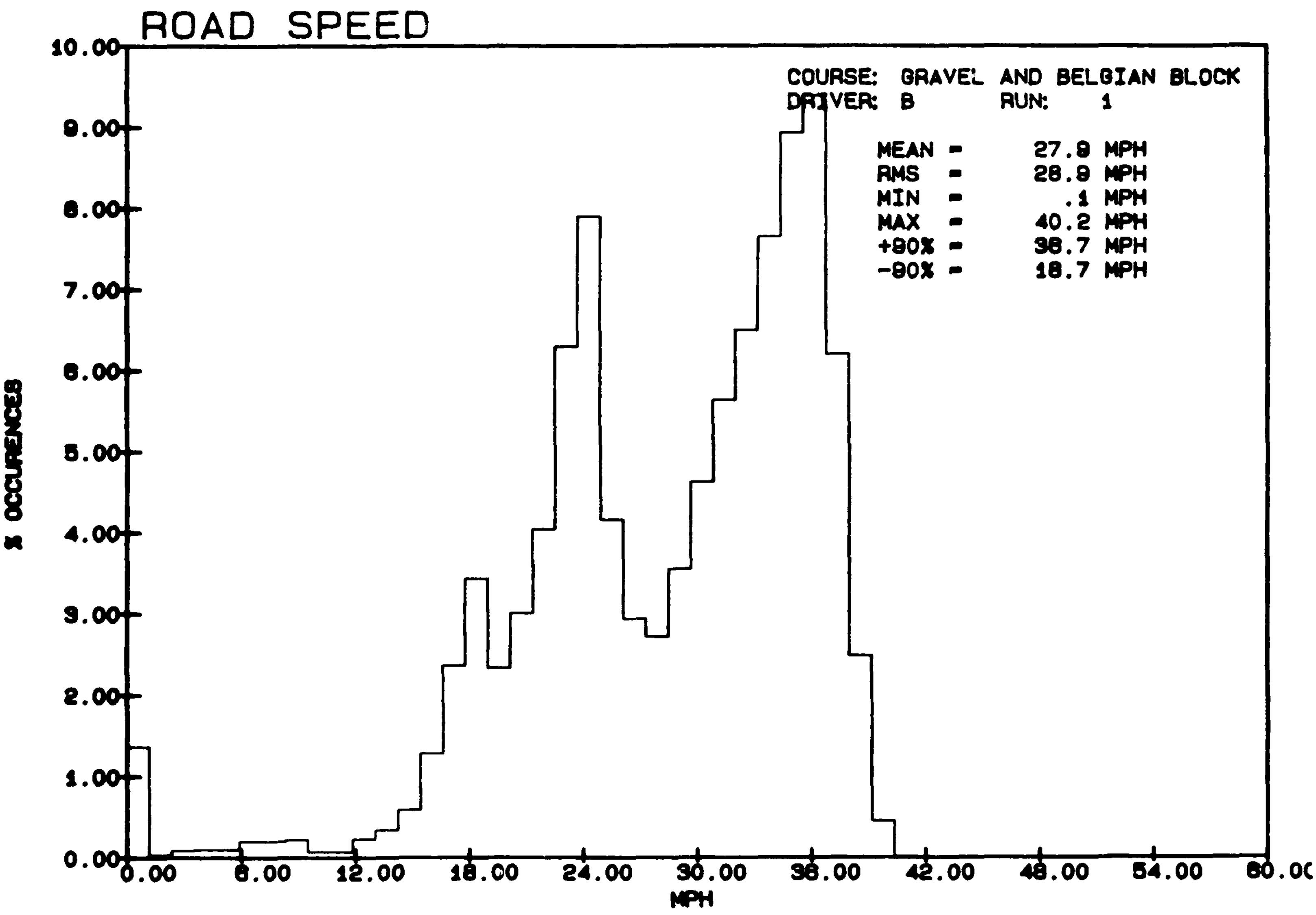
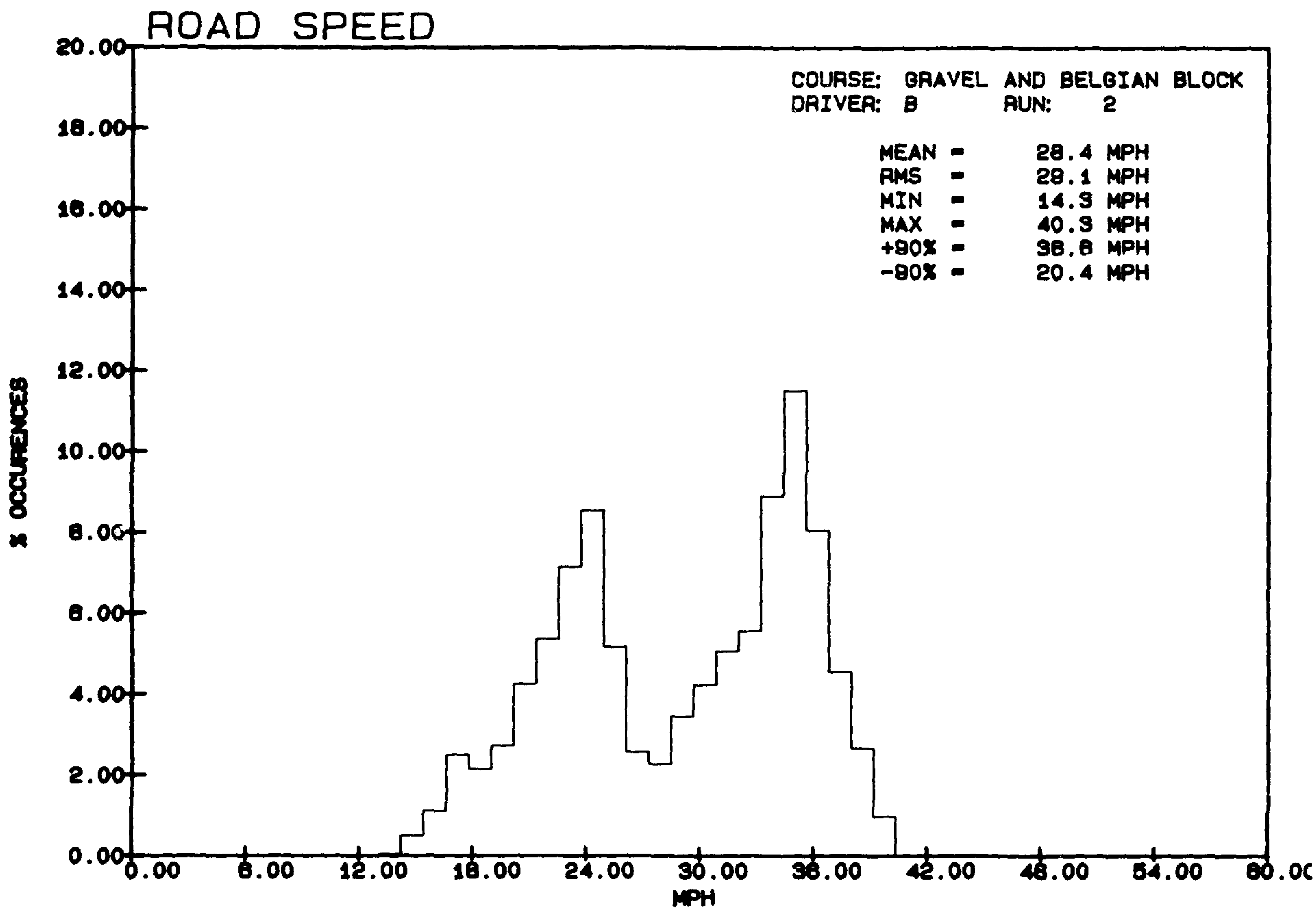
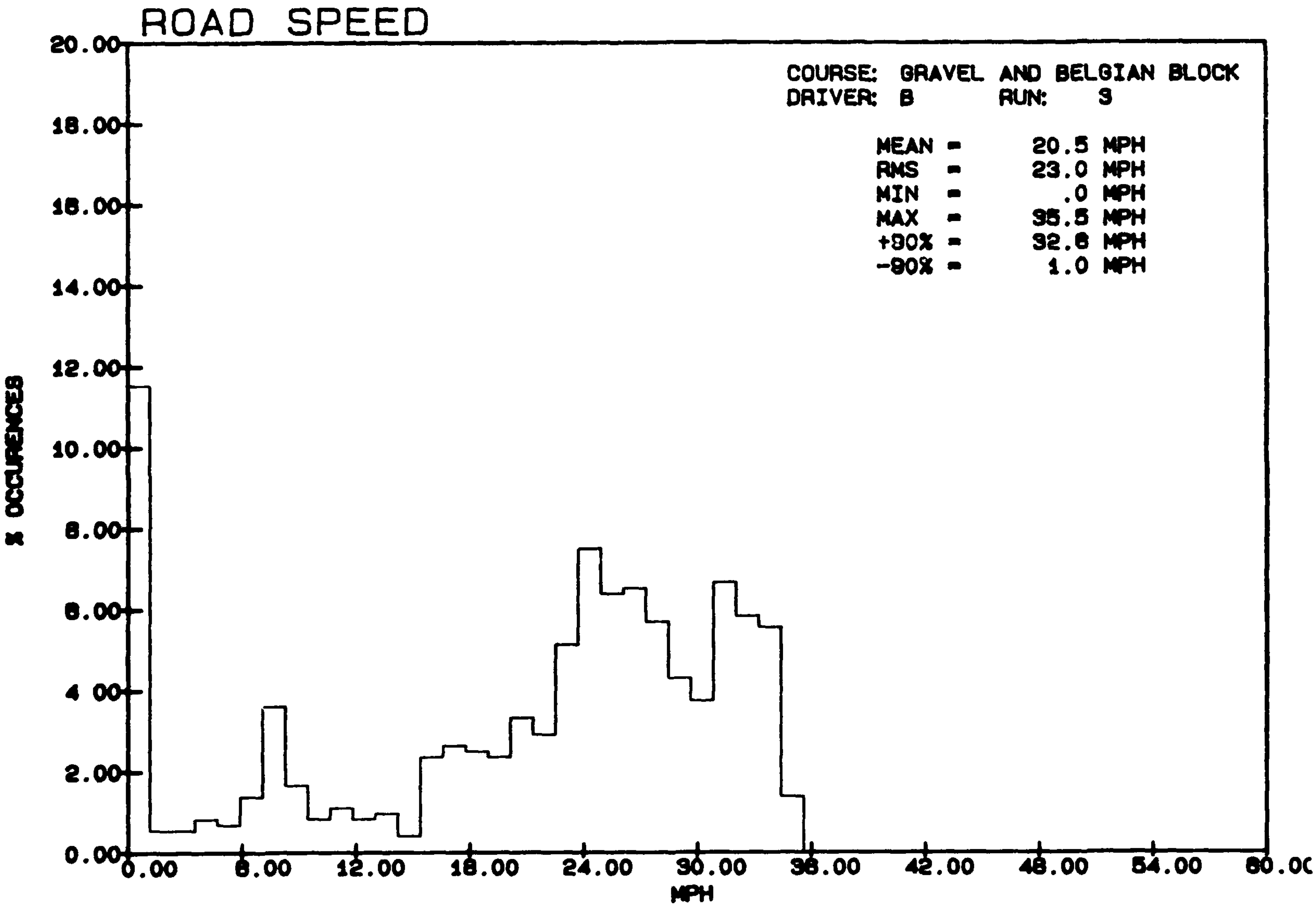

ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 1
MEAN = 27.9 MPH
RMS = 28.9 MPH
MIN = .1 MPH
MAX = 40.2 MPH
+90% = 38.7 MPH
-90% = 18.7 MPH
% OCCURENCES
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
MPH

Figure B-27



ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 2
MEAN = 28.4 MPH
RMS = 29.1 MPH
MIN = 14.3 MPH
MAX = 40.3 MPH
+90% = 38.6 MPH
-90% = 20.4 MPH
% OCCURENCES
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
MPH

Figure B-28



ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 3
MEAN = 20.5 MPH
RMS = 23.0 MPH
MIN = .0 MPH
MAX = 35.5 MPH
+90% = 32.6 MPH
-90% = 1.0 MPH
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
MPH

Figure B-29

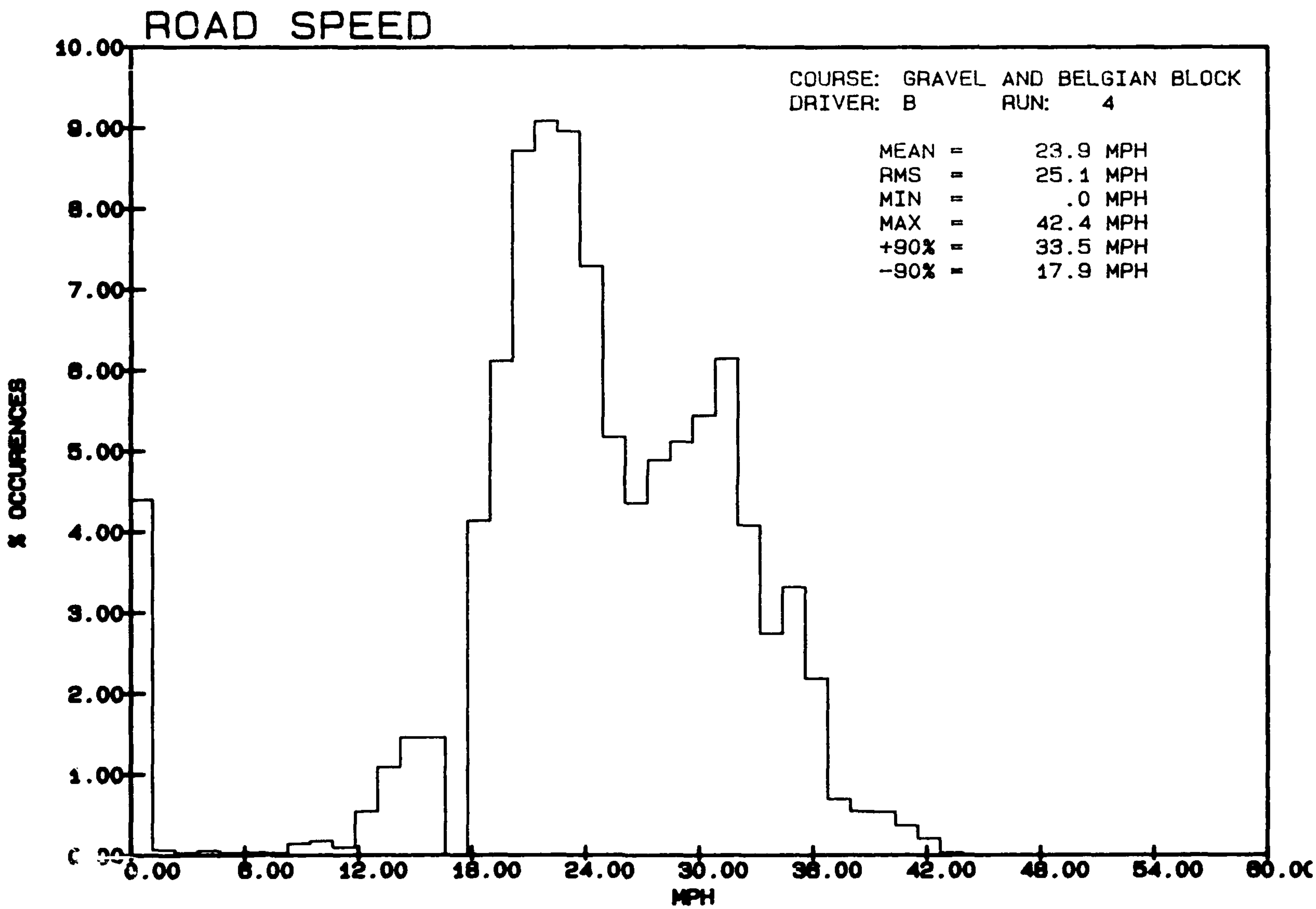

ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 4
MEAN = 23.9 MPH
RMS = 25.1 MPH
MIN = .0 MPH
MAX = 42.4 MPH
+90% = 33.5 MPH
-90% = 17.9 MPH
% OCCURENCES
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
MPH

Figure B-30

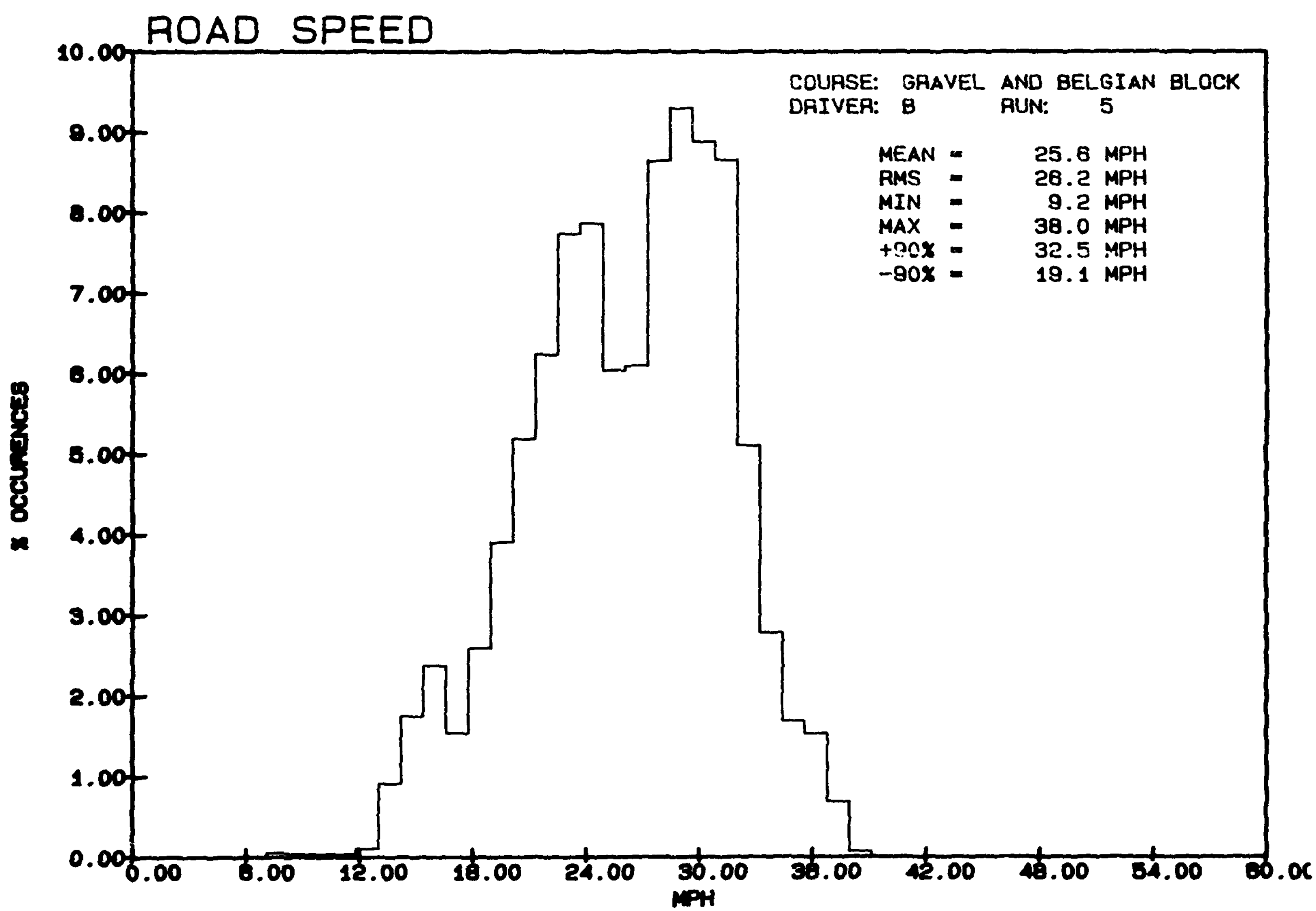

ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 5
MEAN = 25.6 MPH
RMS = 26.2 MPH
MIN = 9.2 MPH
MAX = 38.0 MPH
+90% = 32.5 MPH
-90% = 19.1 MPH
% OCCURENCES
MPH
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00

Figure B-31

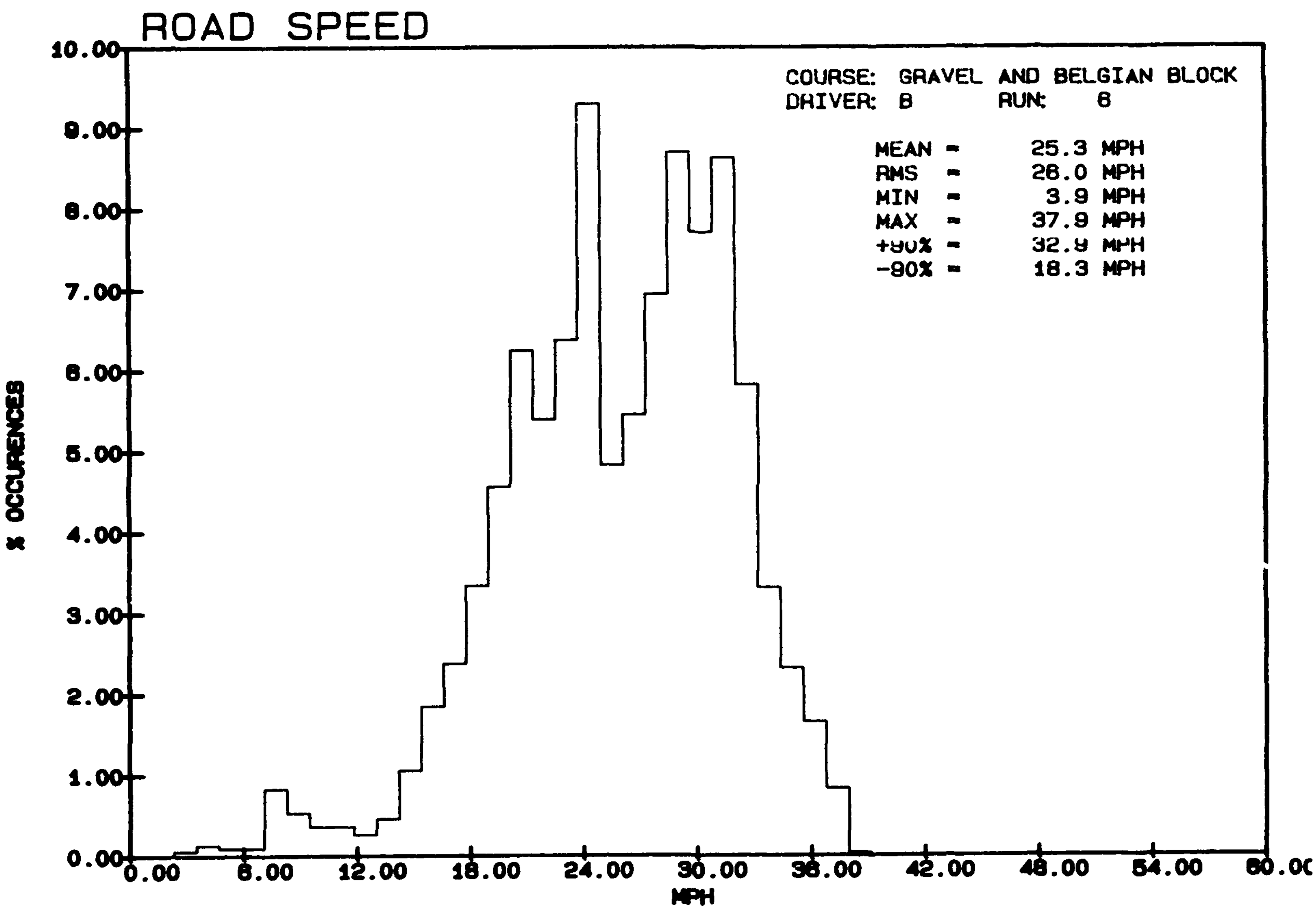

ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 6
MEAN = 25.3 MPH
RMS = 26.0 MPH
MIN = 3.9 MPH
MAX = 37.9 MPH
+90% = 32.9 MPH
-90% = 18.3 MPH
% OCCURENCES
MPH
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00

Figure B-32

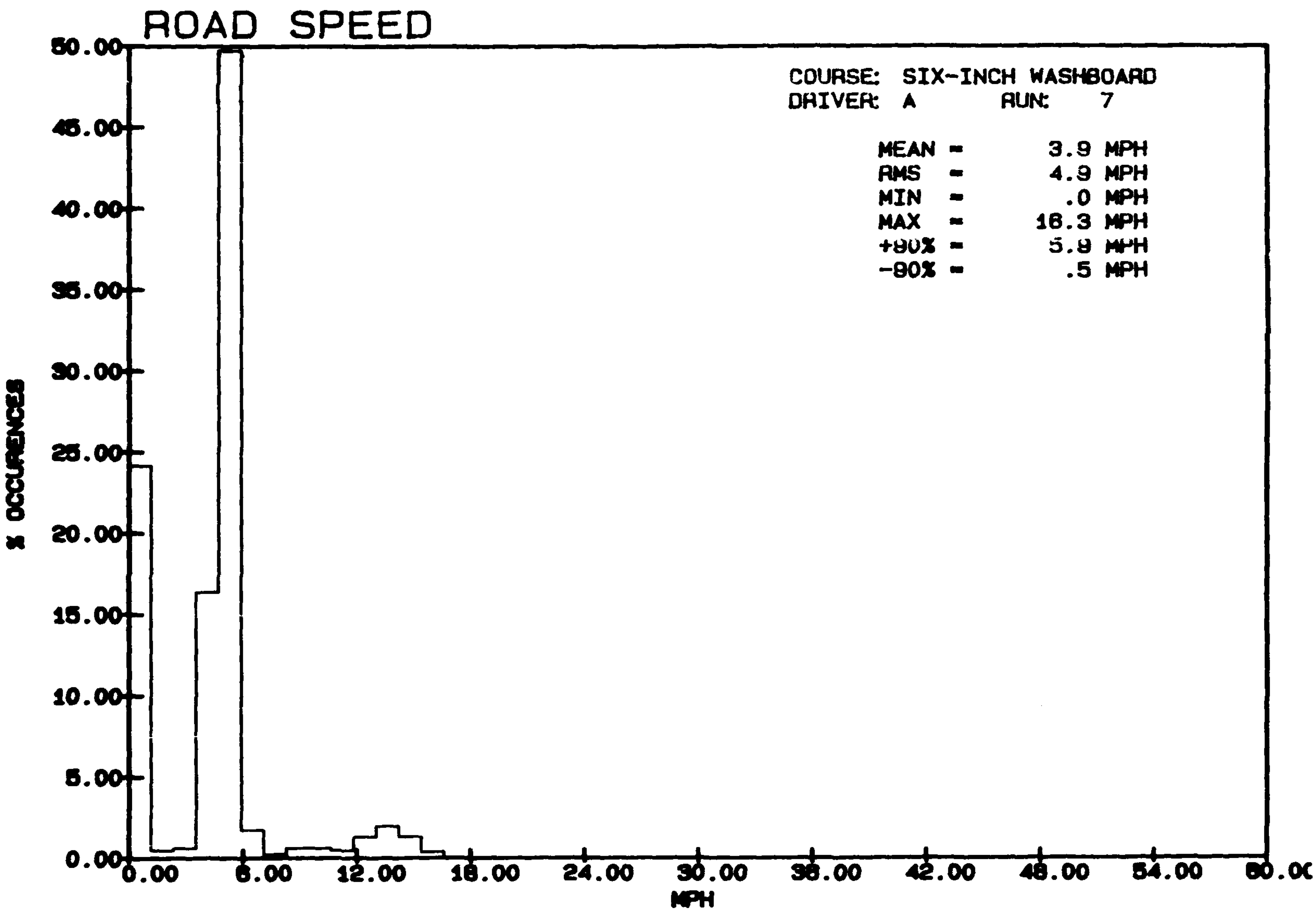

ROAD SPEED
COURSE: SIX-INCH WASHBOARD
DRIVER: A RUN: 7
MEAN = 3.9 MPH
RMS = 4.9 MPH
MIN = .0 MPH
MAX = 16.3 MPH
+90% = 5.9 MPH
-90% = .5 MPH
% OCCURENCES
MPH
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00

Figure B-33

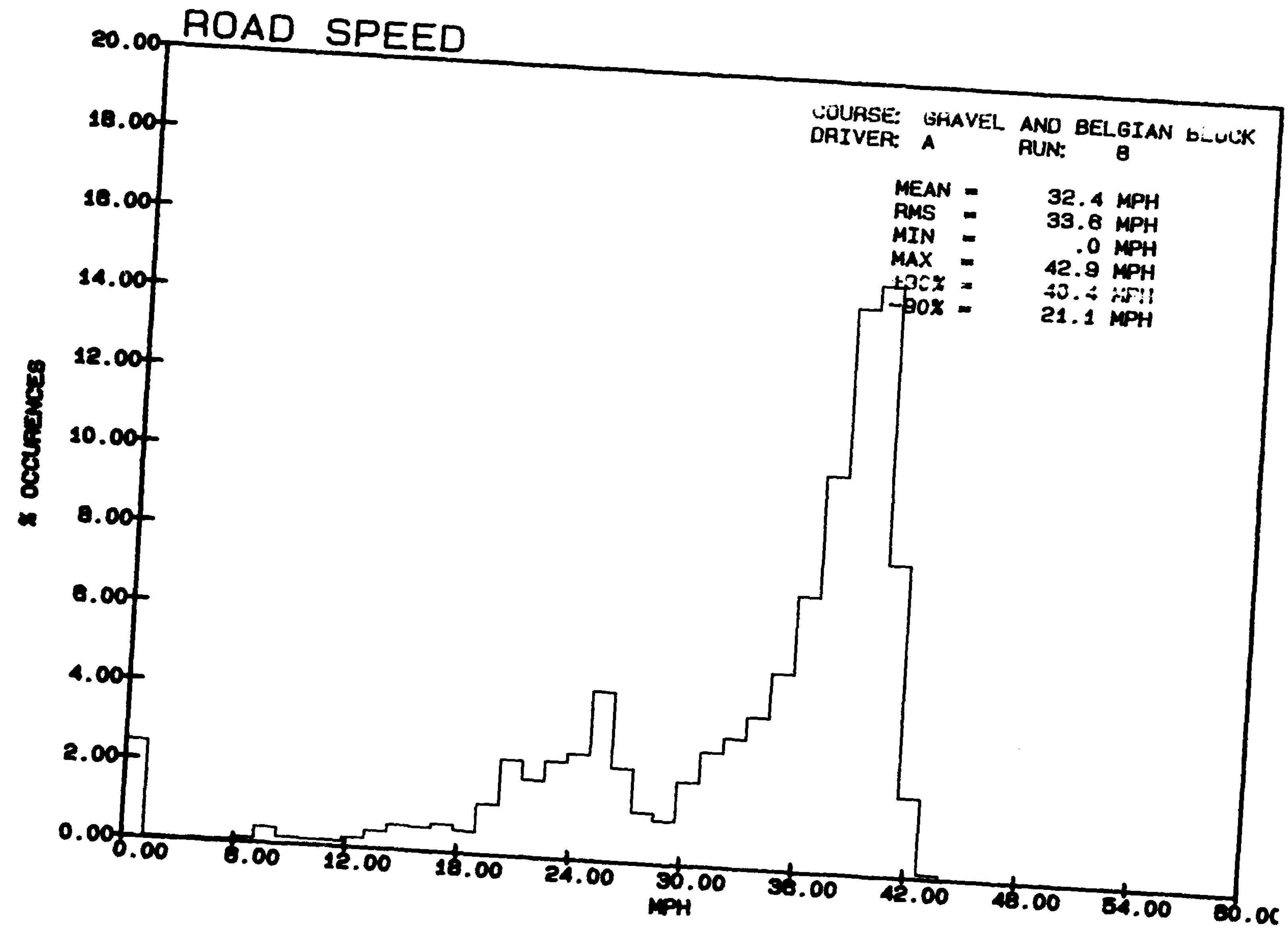

ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 8
MEAN = 32.4 MPH
RMS = 33.6 MPH
MIN = .0 MPH
MAX = 42.9 MPH
-90% = 21.1 MPH
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
MPH

Figure B-34

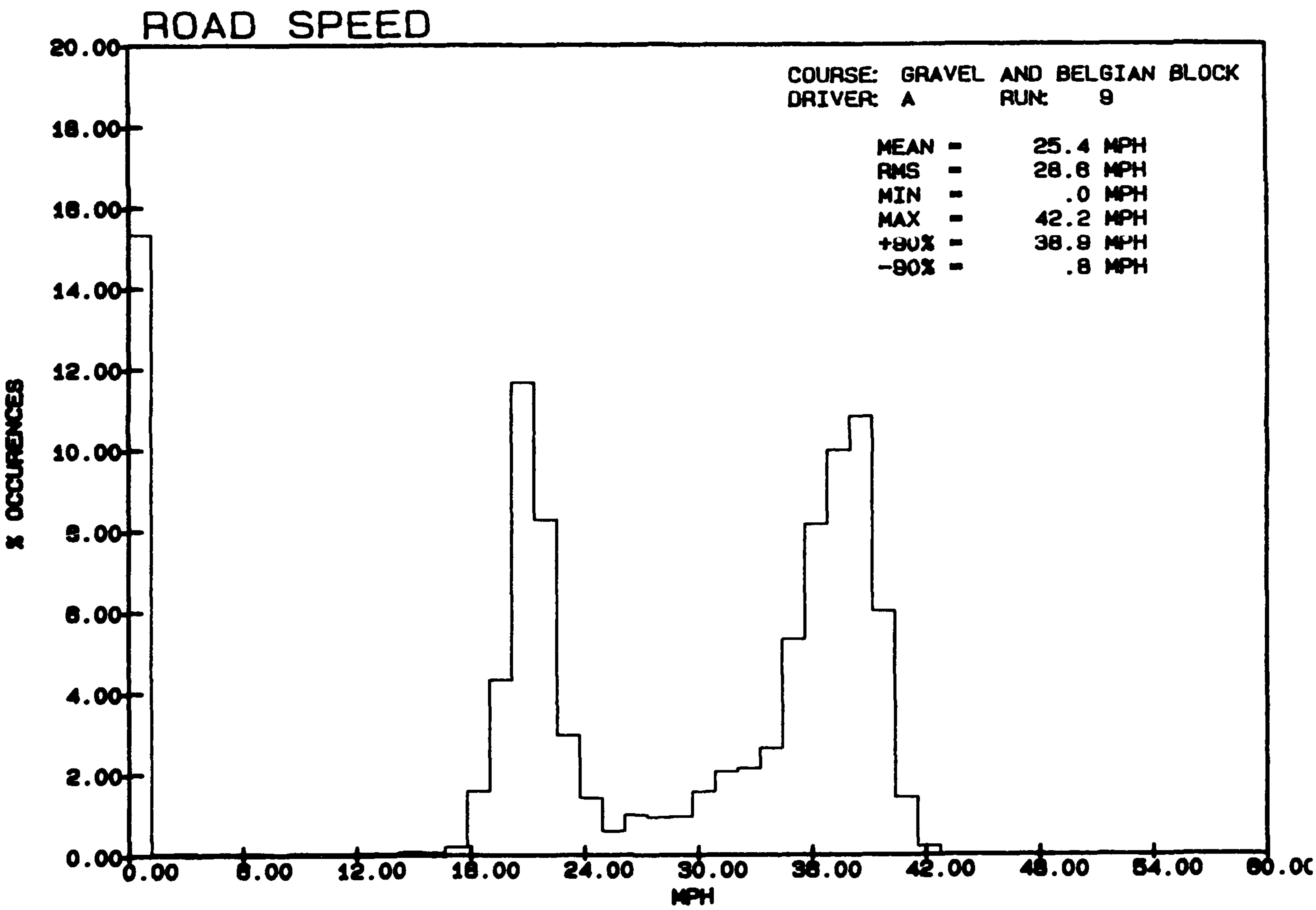

ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 9
MEAN = 25.4 MPH
RMS = 28.6 MPH
MIN = .0 MPH
MAX = 42.2 MPH
+90% = 38.9 MPH
-90% = .8 MPH
% OCCURENCES
MPH
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
2.00
4.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure B-35

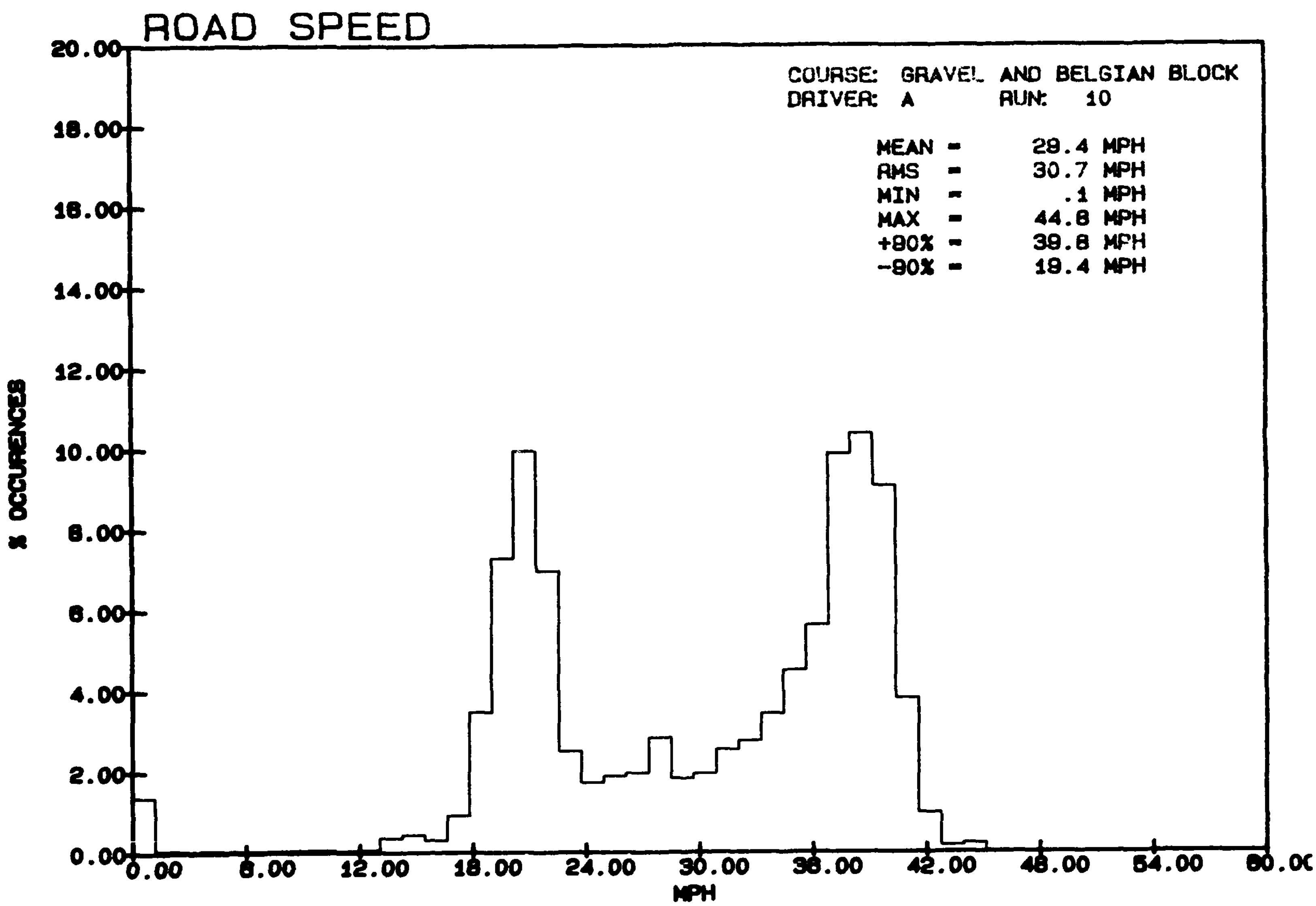

ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 10
MEAN = 29.4 MPH
RMS = 30.7 MPH
MIN = .1 MPH
MAX = 44.8 MPH
+90% = 39.8 MPH
-90% = 19.4 MPH
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
MPH

Figure B-36

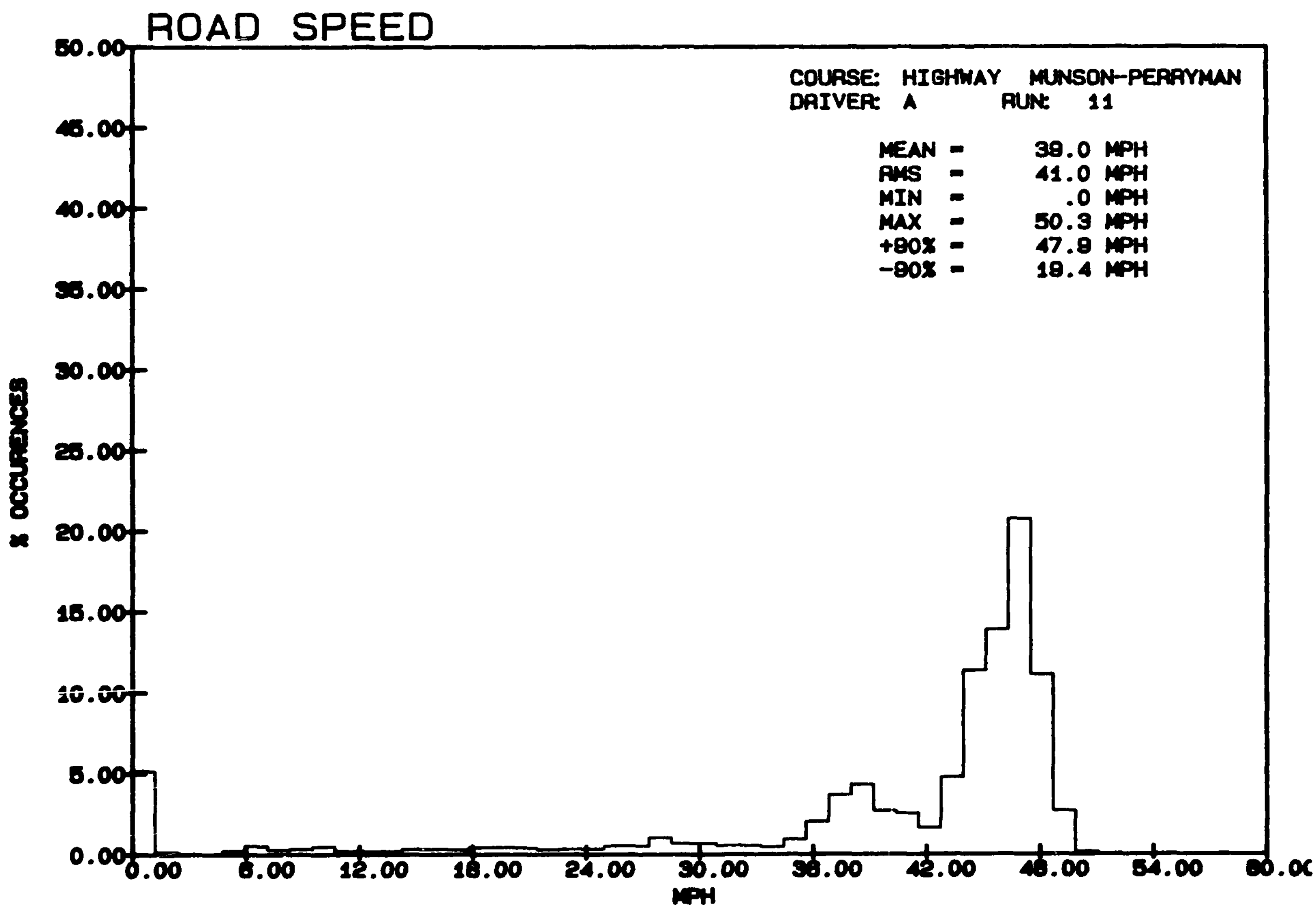
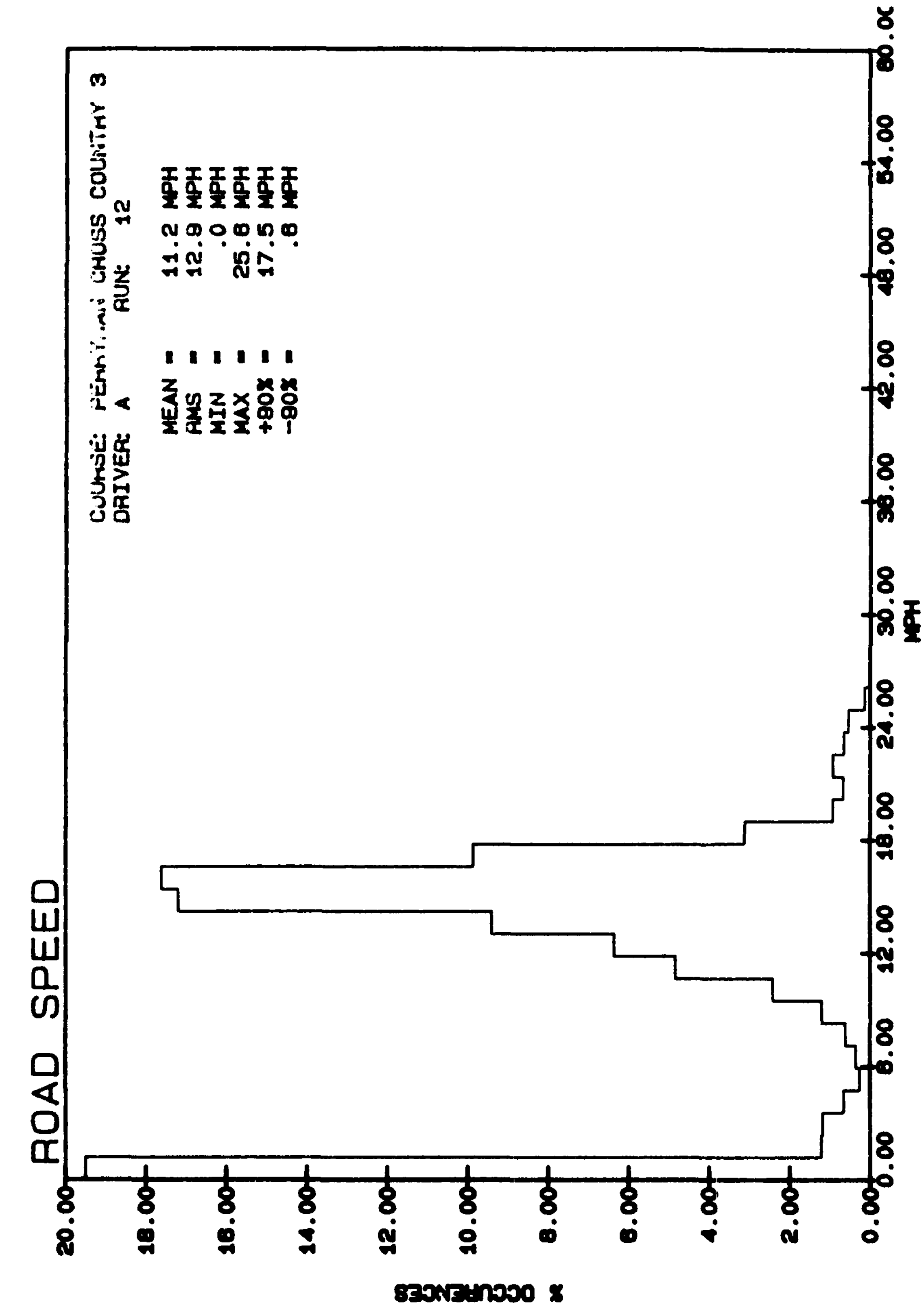

ROAD SPEED
COURSE: HIGHWAY MUNSON-PERRYMAN
DRIVER: A RUN: 11
MEAN = 39.0 MPH
RMS = 41.0 MPH
MIN = .0 MPH
MAX = 50.3 MPH
+90% = 47.9 MPH
-90% = 19.4 MPH
% OCCURENCES
MPH
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00

Figure B-37



ROAD SPEED
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A
RUN: 12
MEAN = 11.2 MPH
RMS = 12.9 MPH
MIN = .0 MPH
MAX = 25.8 MPH
+90% = 17.5 MPH
-90% = .8 MPH
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
MPH

Figure B-38

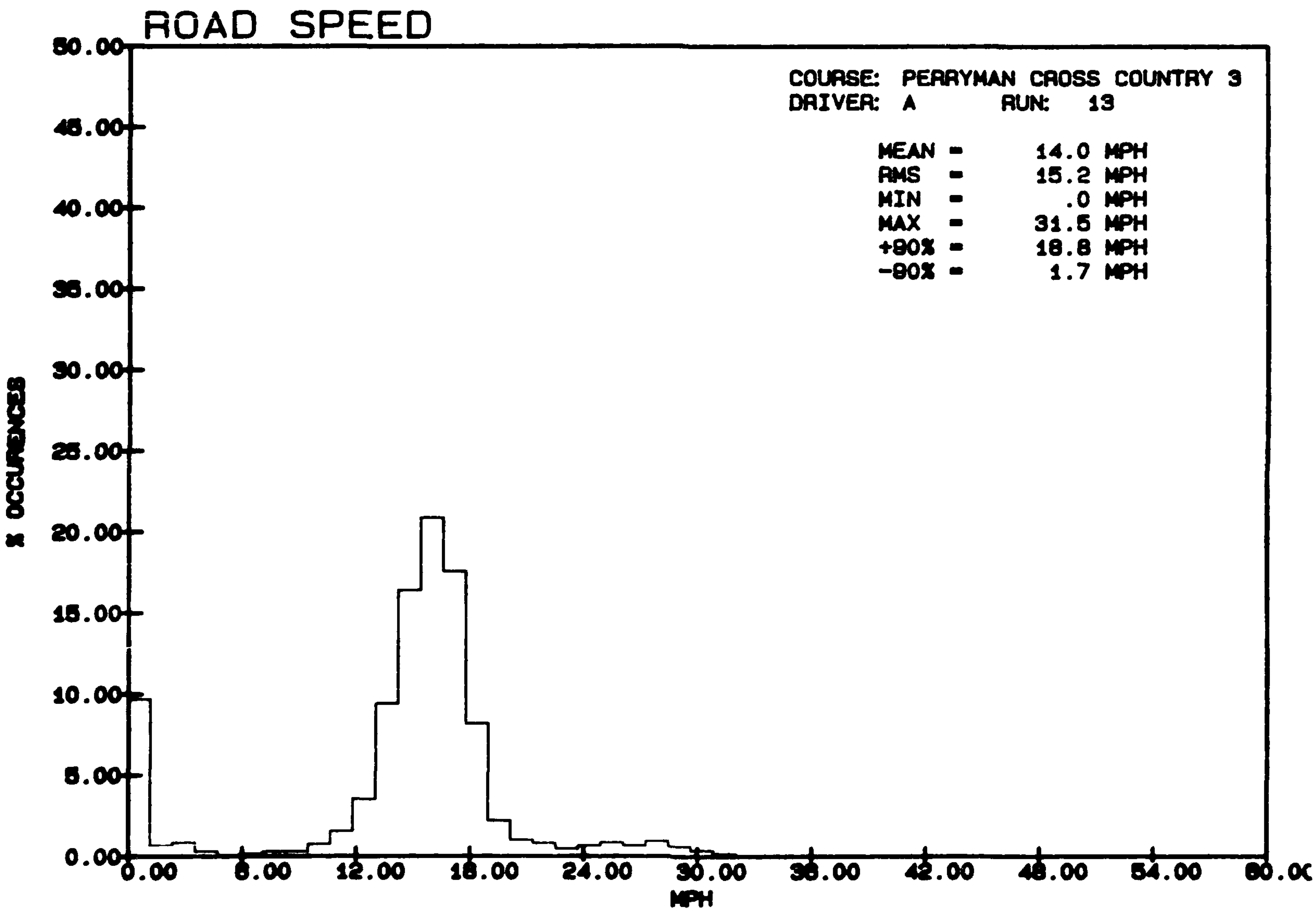

ROAD SPEED
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 13
MEAN = 14.0 MPH
RMS = 15.2 MPH
MIN = .0 MPH
MAX = 31.5 MPH
+90% = 18.8 MPH
-90% = 1.7 MPH
% OCCURENCES
MPH

Figure B-39

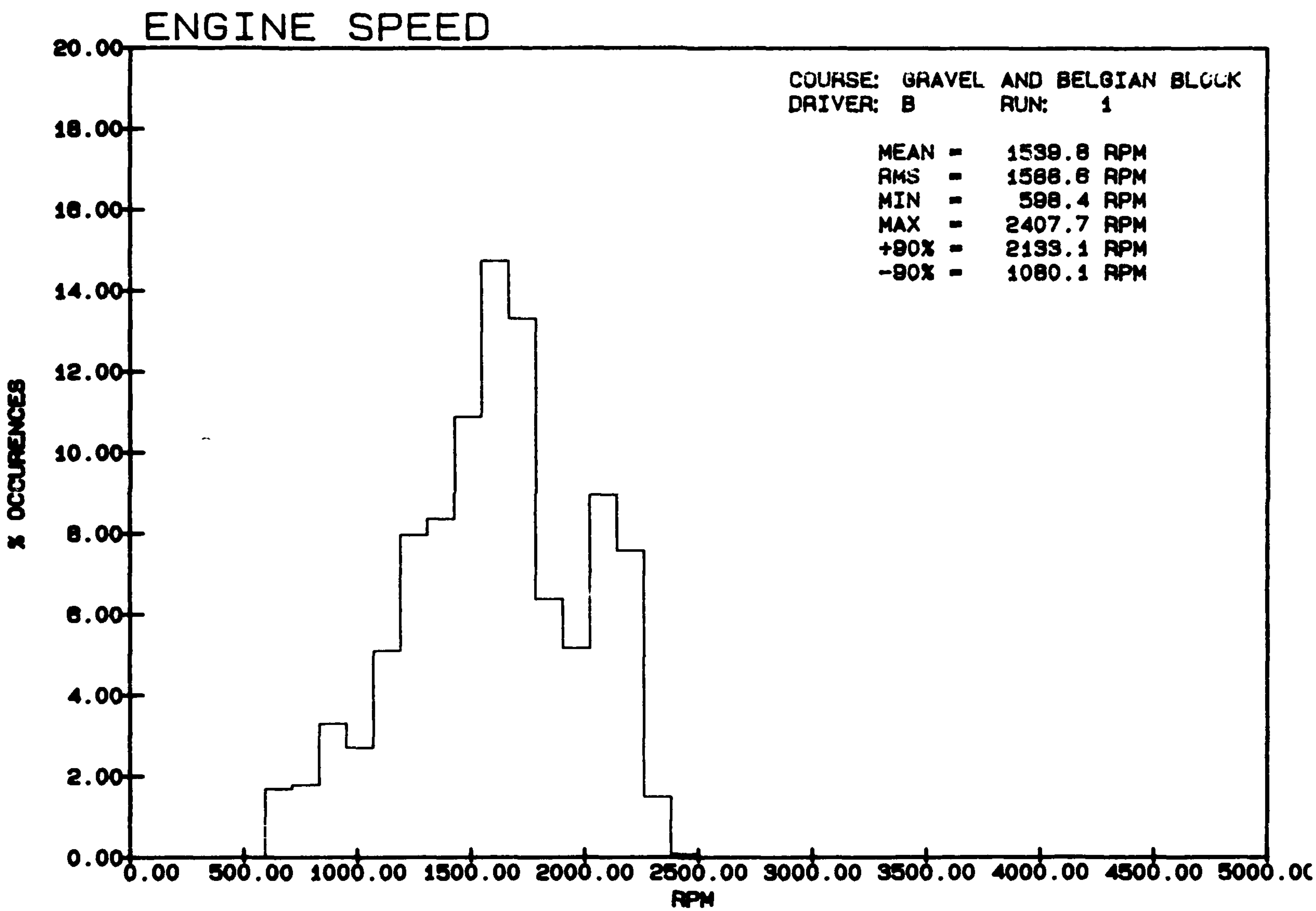
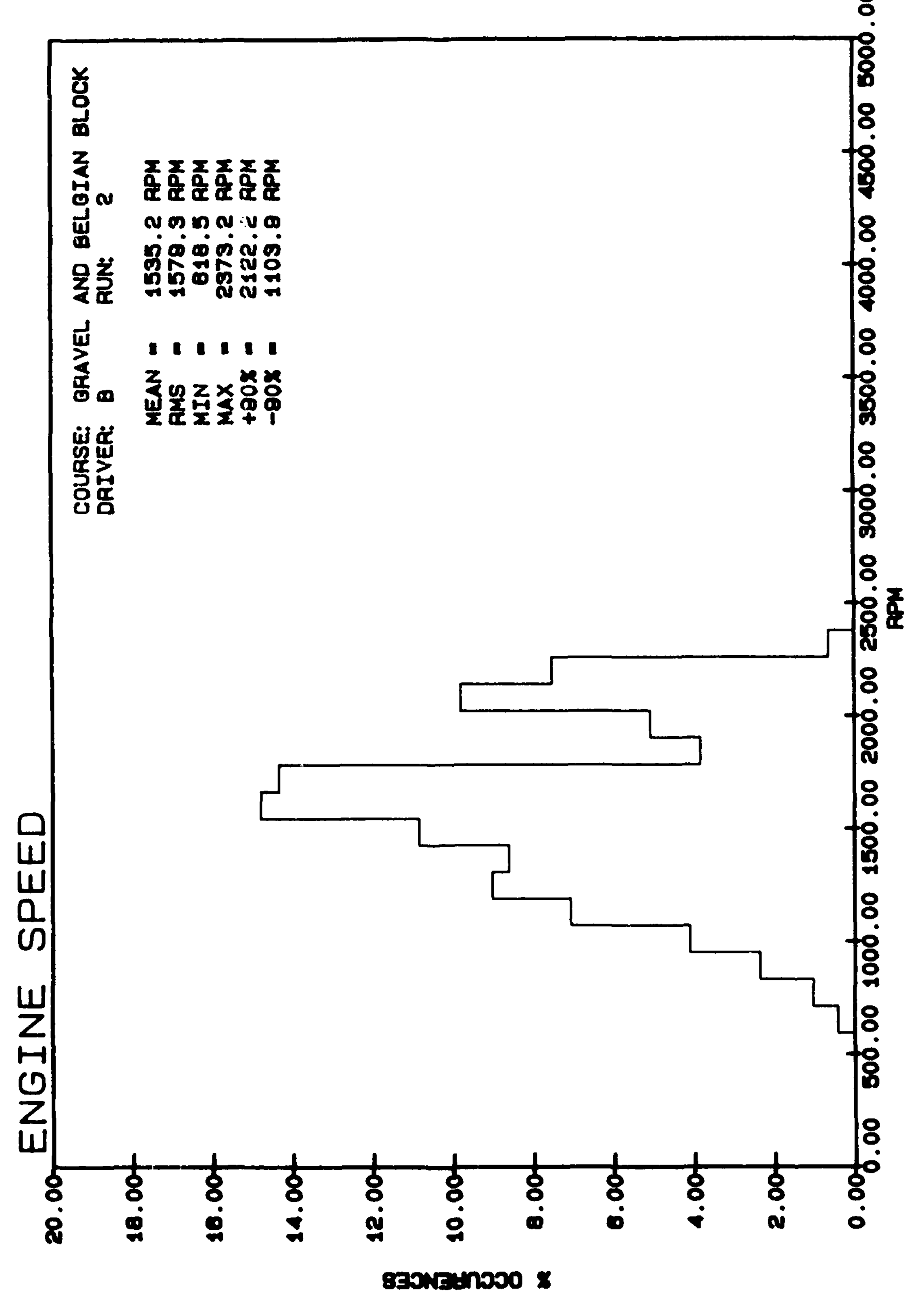
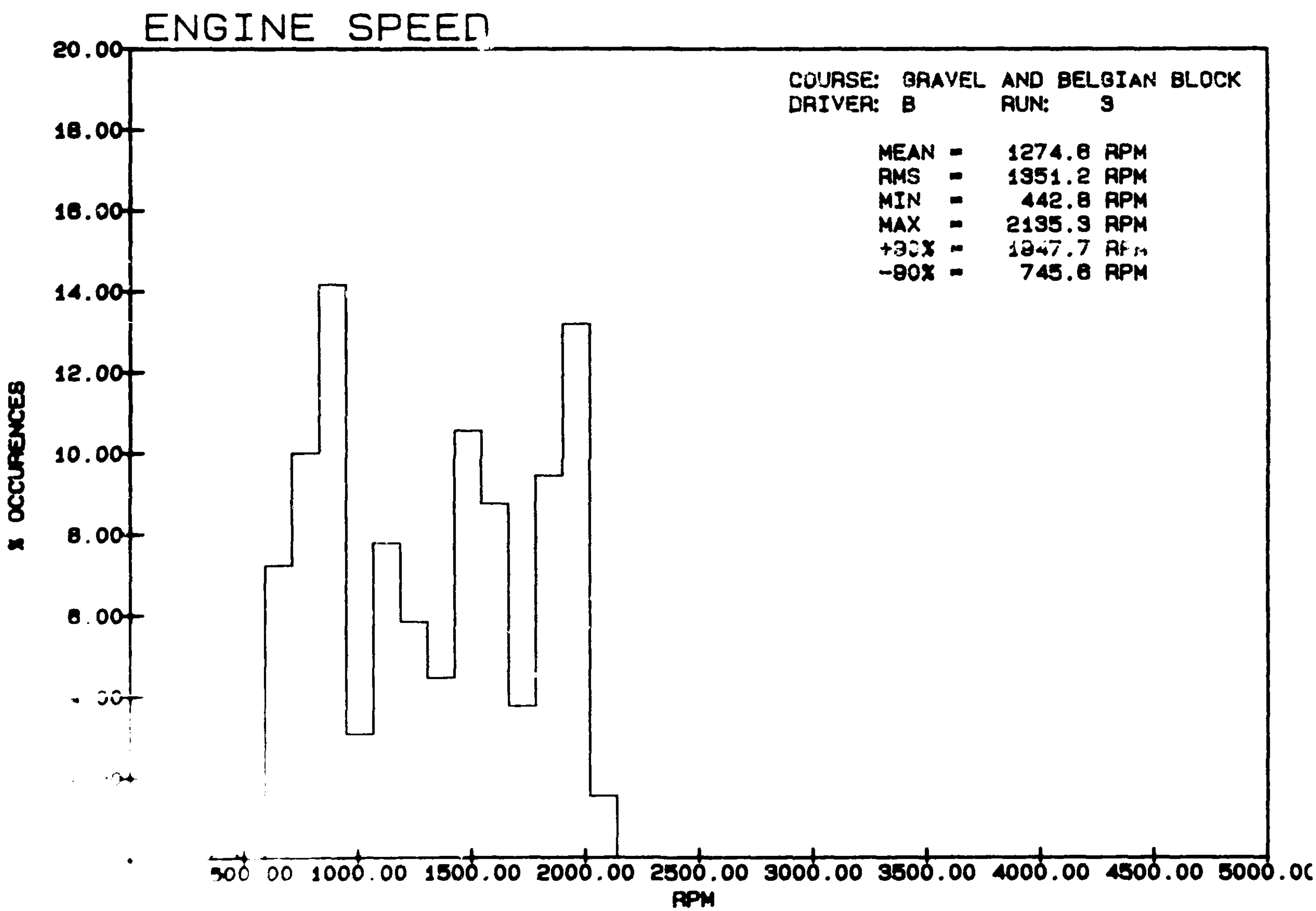

ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 1
MEAN = 1539.8 RPM
RMS = 1588.6 RPM
MIN = 598.4 RPM
MAX = 2407.7 RPM
+90% = 2133.1 RPM
-90% = 1080.1 RPM
% OCCURENCES
RPM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00

Figure B-40



ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 2
MEAN = 1535.2 RPM
RMS = 1579.3 RPM
MIN = 618.5 RPM
MAX = 2373.2 RPM
+90% = 2122.2 RPM
-90% = 1103.8 RPM
% OCCURENCES
RPM
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00

Figure B-41



ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 3
MEAN = 1274.8 RPM
RMS = 1351.2 RPM
MIN = 442.8 RPM
MAX = 2135.3 RPM
+90% = 1847.7 RPM
-90% = 745.8 RPM
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00
RPM

Figure B-42

AD-A142 458 VEHICLE PERFORMANCE RECORDER (VPR)/ HMMWV (HIGH MOBILITY MULTI-PURPOSE WH..(U) ABERDEEN PROVING GROUND MD MATERIEL TESTING DIRECTORATE S F HARLEY ET AL. 2/2

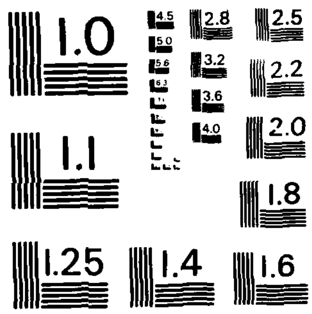
UNCLASSIFIED MAY 84 APG-MT-6007 F/G 14/3 NL

END

DATE FILMED

8 84

DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

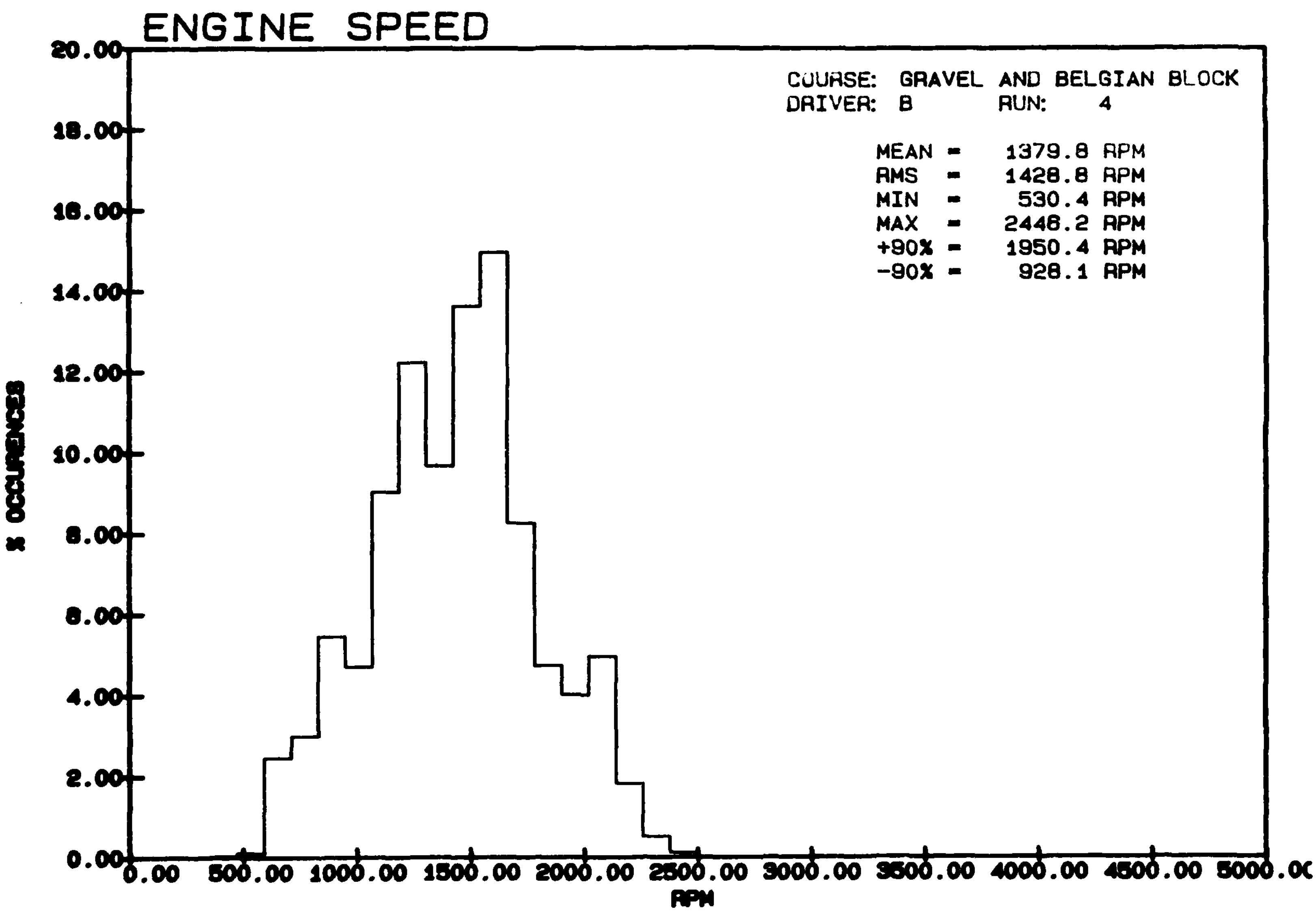

ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 4
MEAN = 1379.8 RPM
RMS = 1428.8 RPM
MIN = 530.4 RPM
MAX = 2448.2 RPM
+90% = 1950.4 RPM
-90% = 928.1 RPM
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00
RPM

Figure B-43

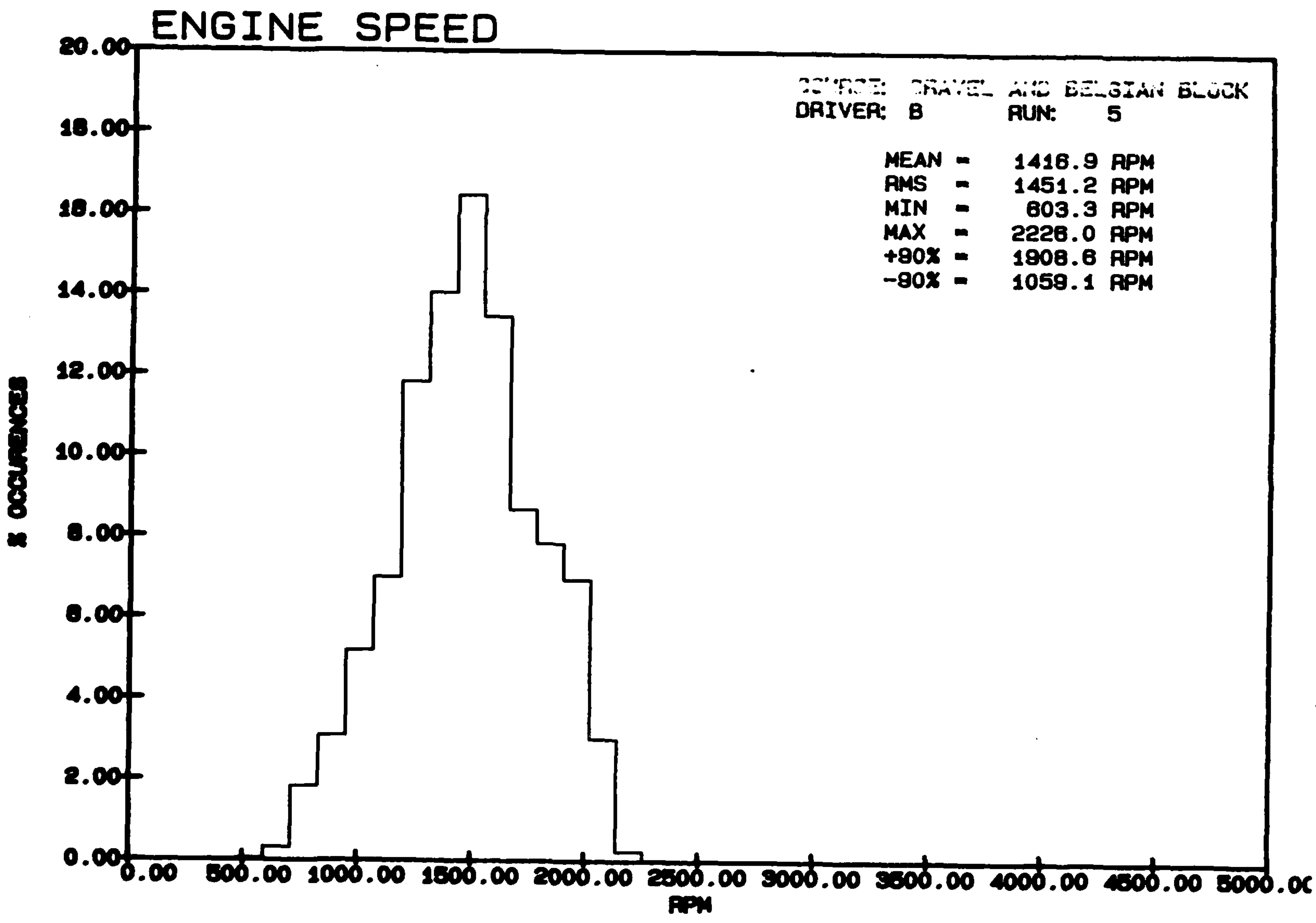

ENGINE SPEED
AND BELGIAN BLOCK
DRIVER: B RUN: 5
MEAN = 1416.9 RPM
RMS = 1451.2 RPM
MIN = 603.3 RPM
MAX = 2226.0 RPM
+90% = 1908.6 RPM
-90% = 1059.1 RPM
% OCCURENCES
RPM
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00

Figure B-44

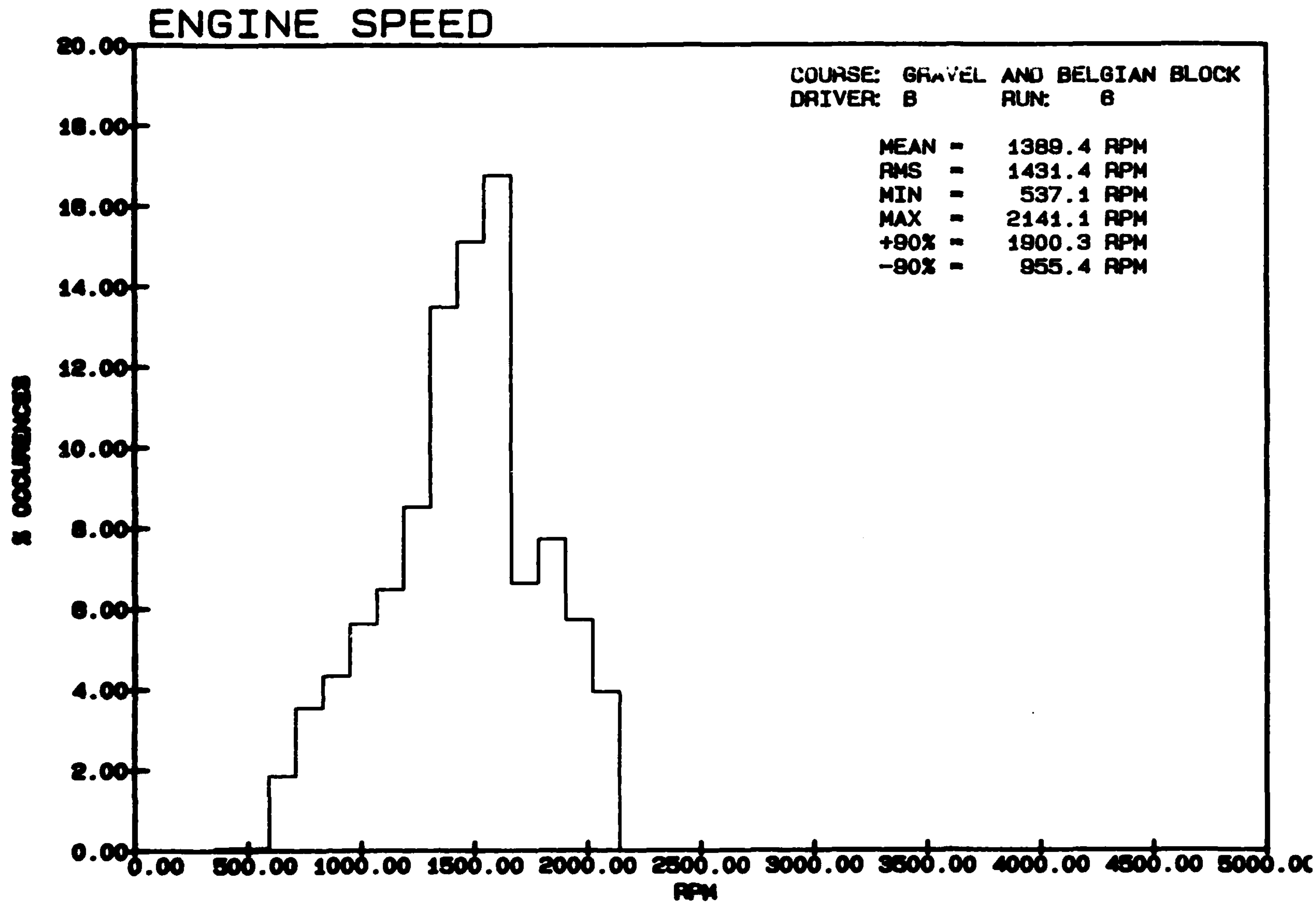

ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 6
MEAN = 1389.4 RPM
RMS = 1431.4 RPM
MIN = 537.1 RPM
MAX = 2141.1 RPM
+90% = 1900.3 RPM
-90% = 855.4 RPM
% OCCURRENCES
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
RPM

Figure B-45

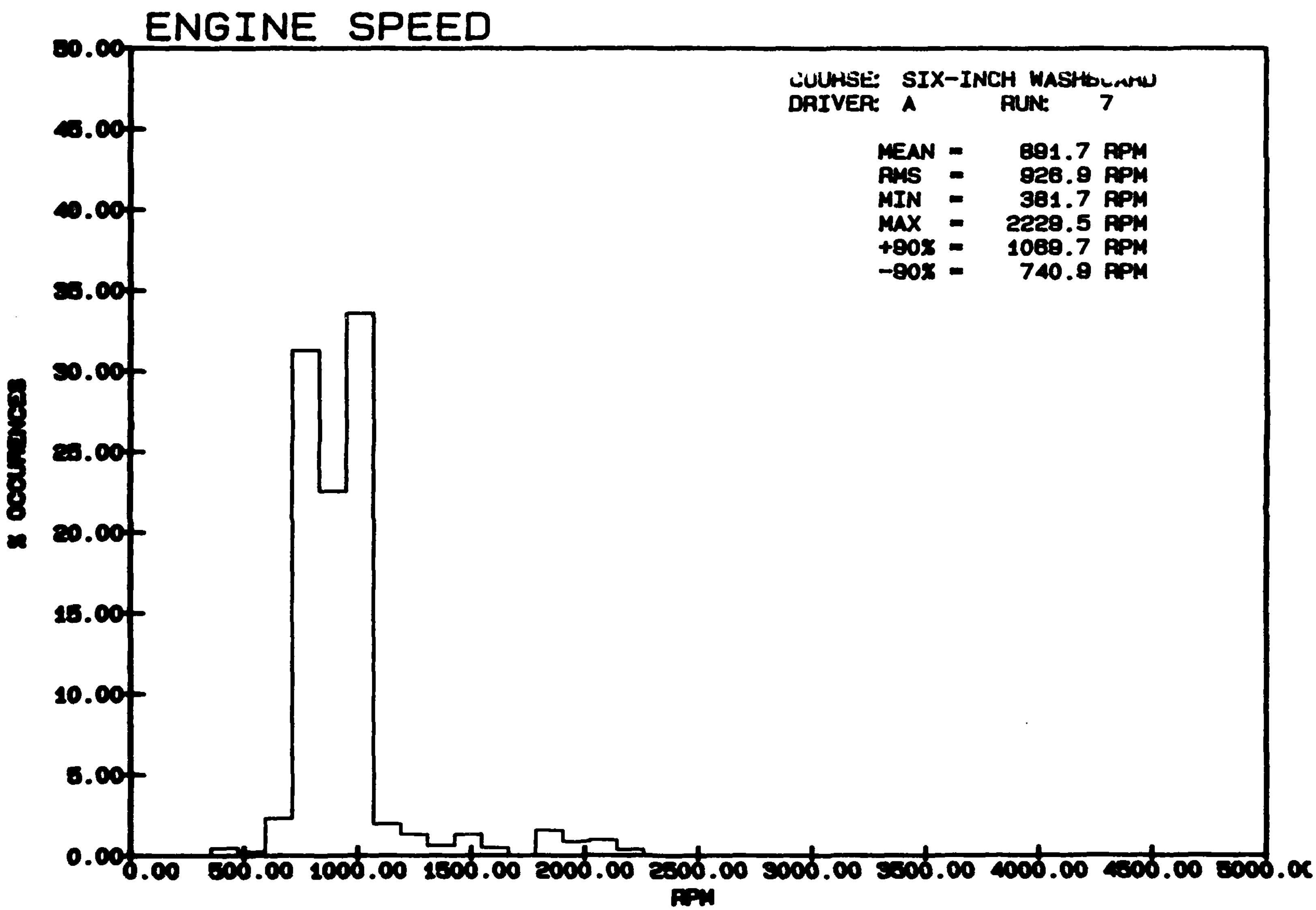

ENGINE SPEED
COURSE: SIX-INCH WASHBOARD
DRIVER: A RUN: 7
MEAN = 891.7 RPM
RMS = 926.9 RPM
MIN = 381.7 RPM
MAX = 2229.5 RPM
+90% = 1069.7 RPM
-90% = 740.9 RPM
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.0C
RPM

Figure B-46

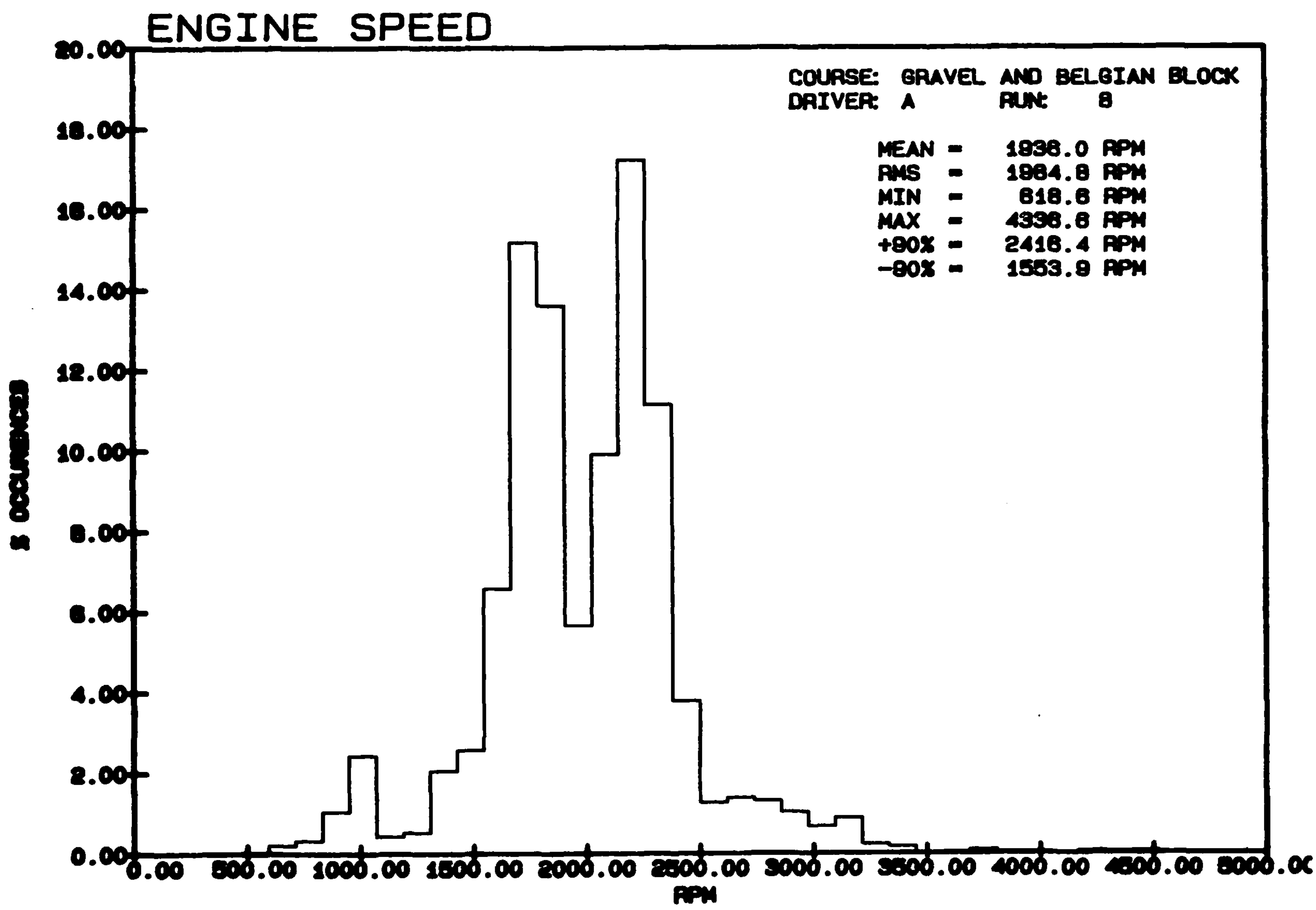

ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 6
MEAN = 1936.0 RPM
RMS = 1964.8 RPM
MIN = 616.6 RPM
MAX = 4336.6 RPM
+90% = 2416.4 RPM
-90% = 1553.9 RPM
% OCCURRENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00
RPM

Figure B-47

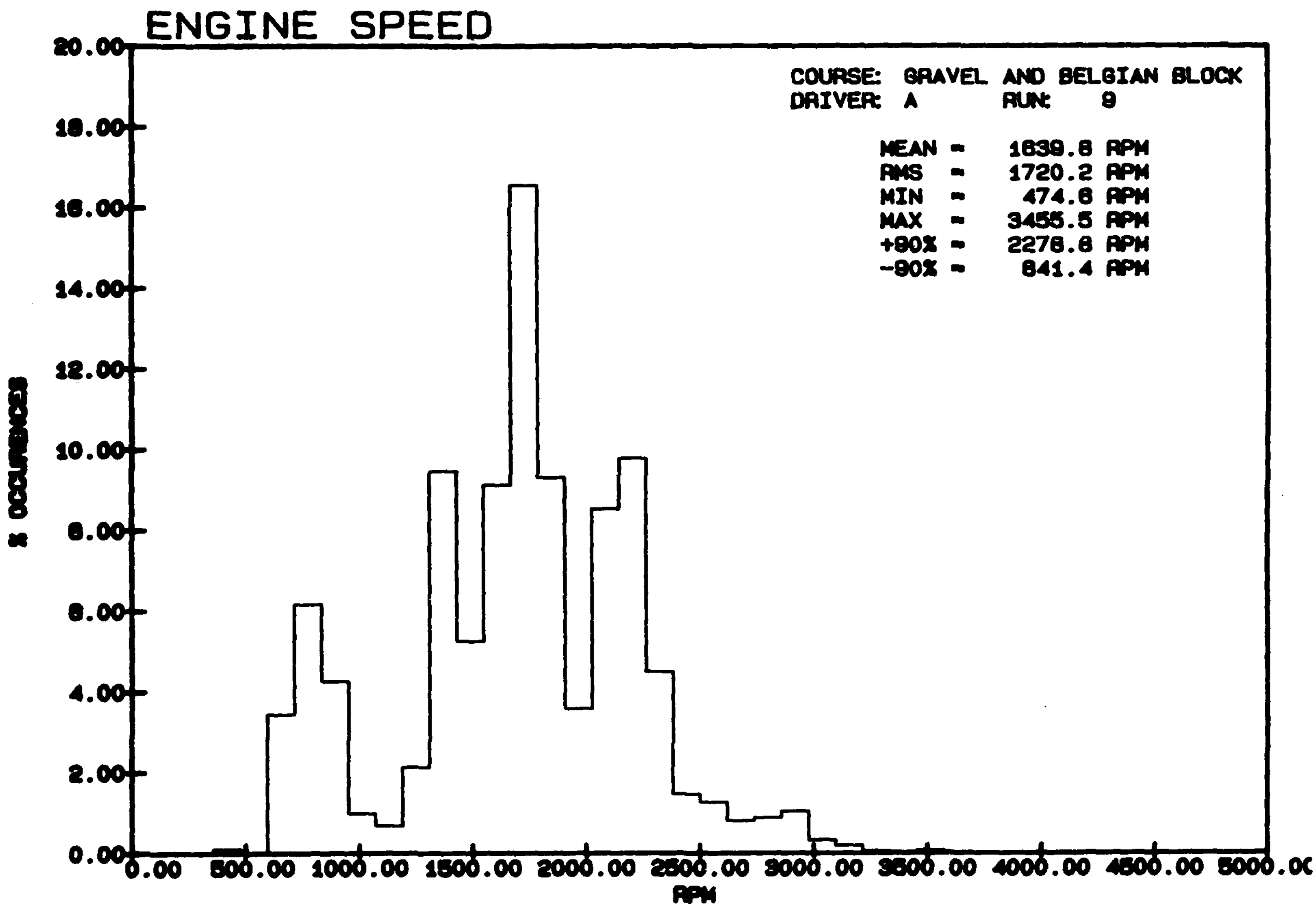

ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 9
MEAN = 1639.8 RPM
RMS = 1720.2 RPM
MIN = 474.6 RPM
MAX = 3455.5 RPM
+90% = 2276.8 RPM
-90% = 841.4 RPM
% OCCURRENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00
RPM

Figure B-48

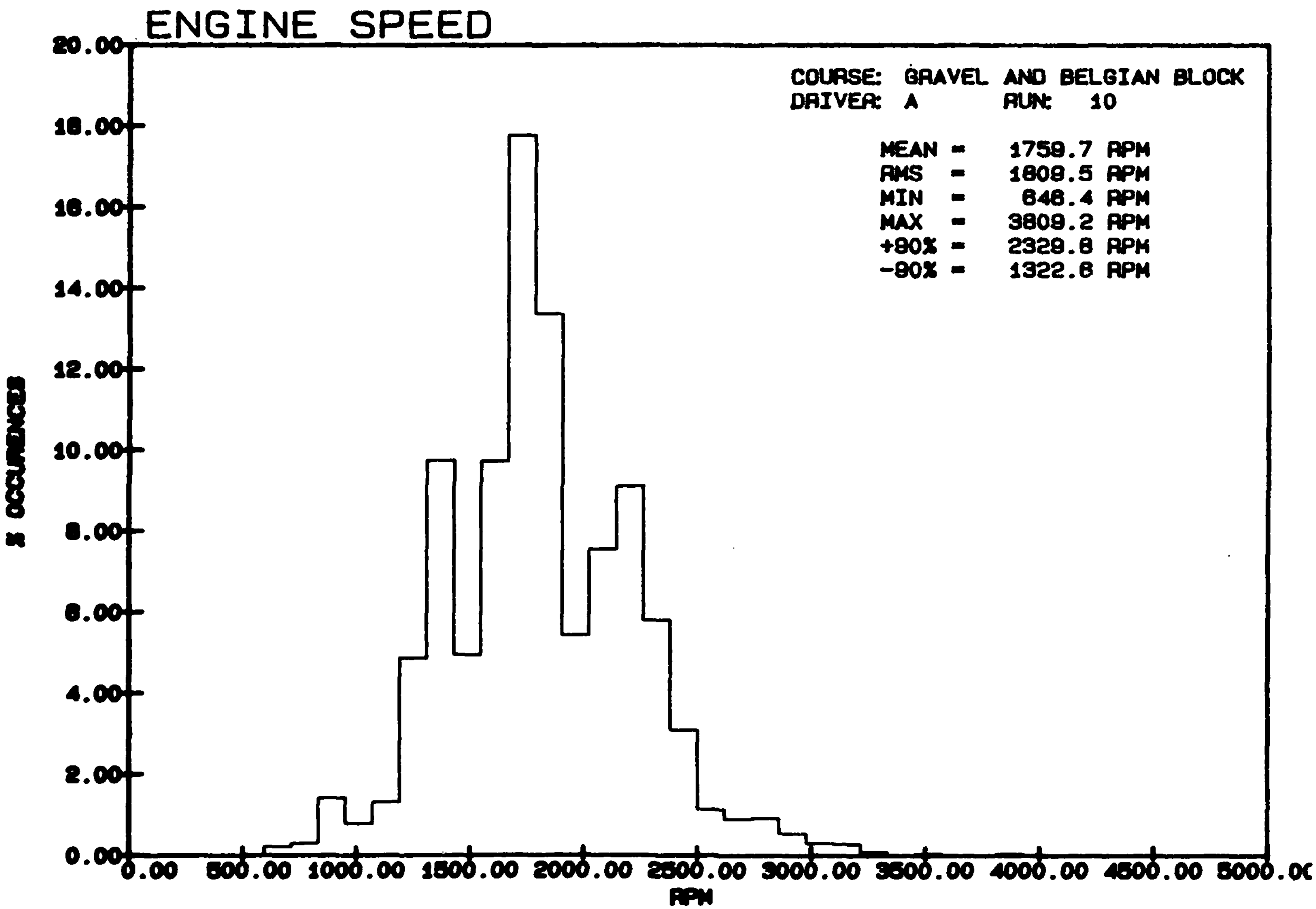

ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 10
MEAN = 1759.7 RPM
RMS = 1808.5 RPM
MIN = 646.4 RPM
MAX = 3809.2 RPM
+90% = 2329.8 RPM
-90% = 1322.6 RPM
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
% OCCURRENCES
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.0
RPM

Figure B-49

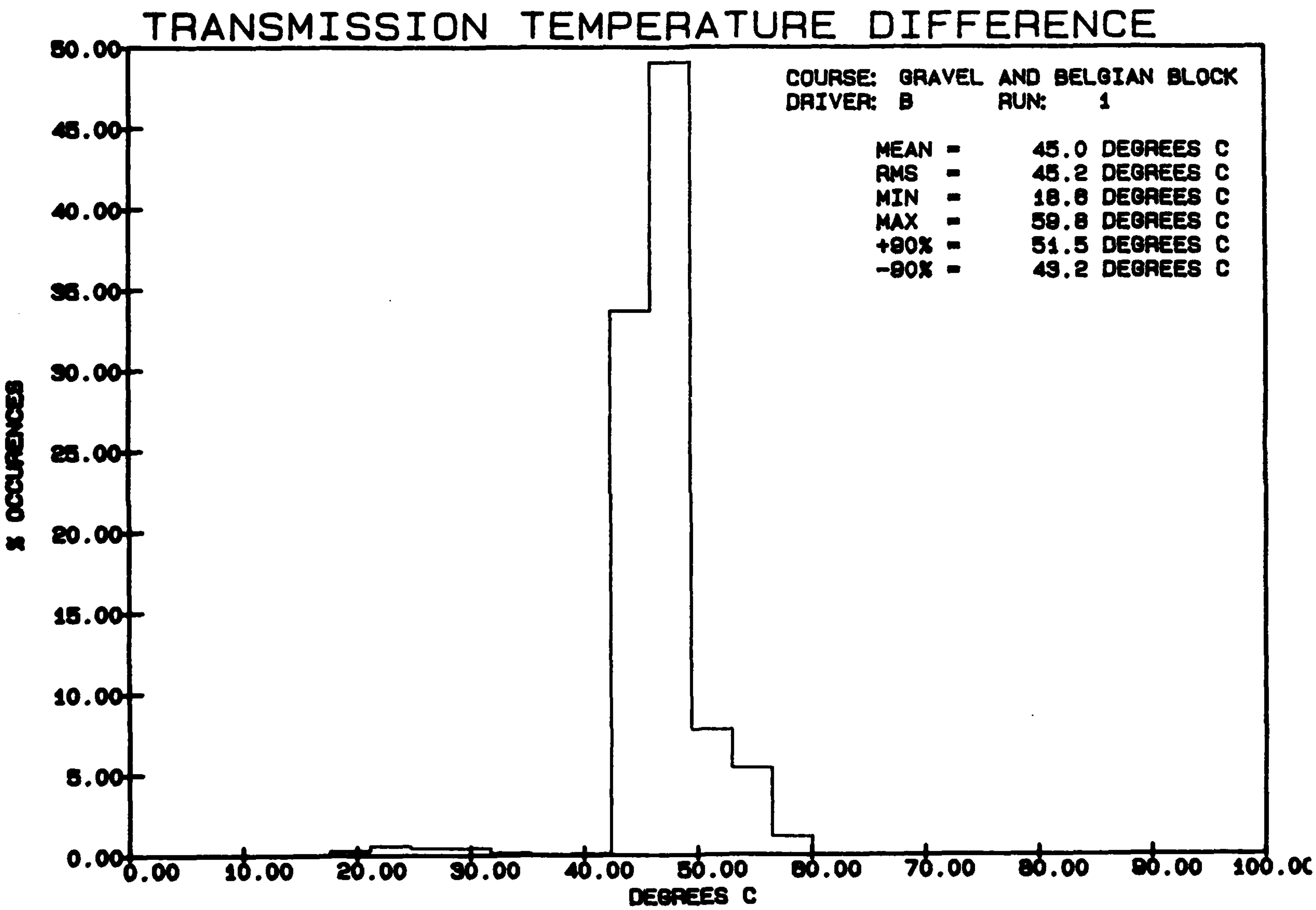

TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 1
MEAN = 45.0 DEGREES C
RMS = 45.2 DEGREES C
MIN = 18.8 DEGREES C
MAX = 59.8 DEGREES C
+90% = 51.5 DEGREES C
-90% = 43.2 DEGREES C
% OCCURENCES
DEGREES C
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
5.00
15.00
25.00
35.00
45.00

Figure B-50

TRANSMISSION TEMPERATURE DIFFERENCE

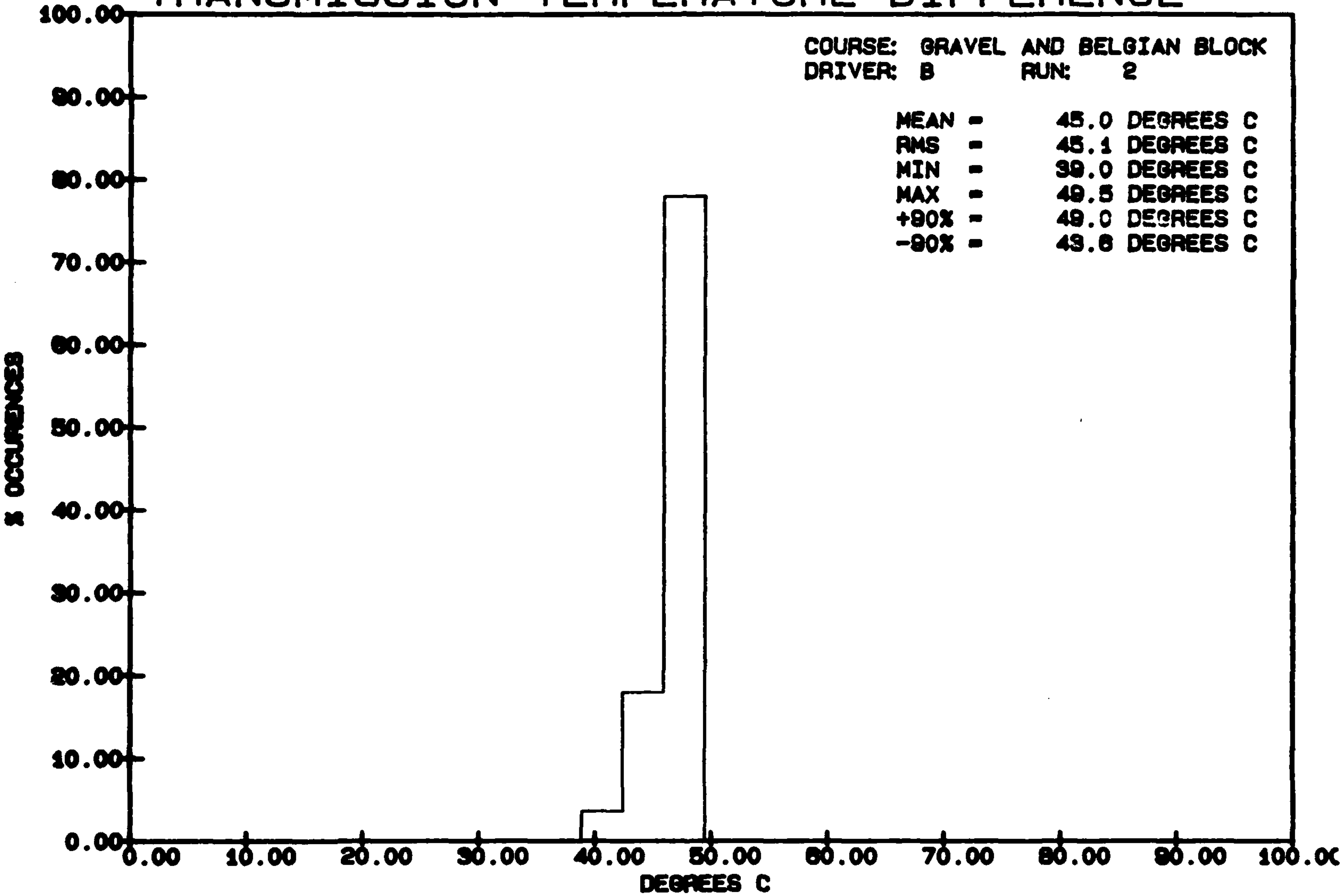


Figure B-51

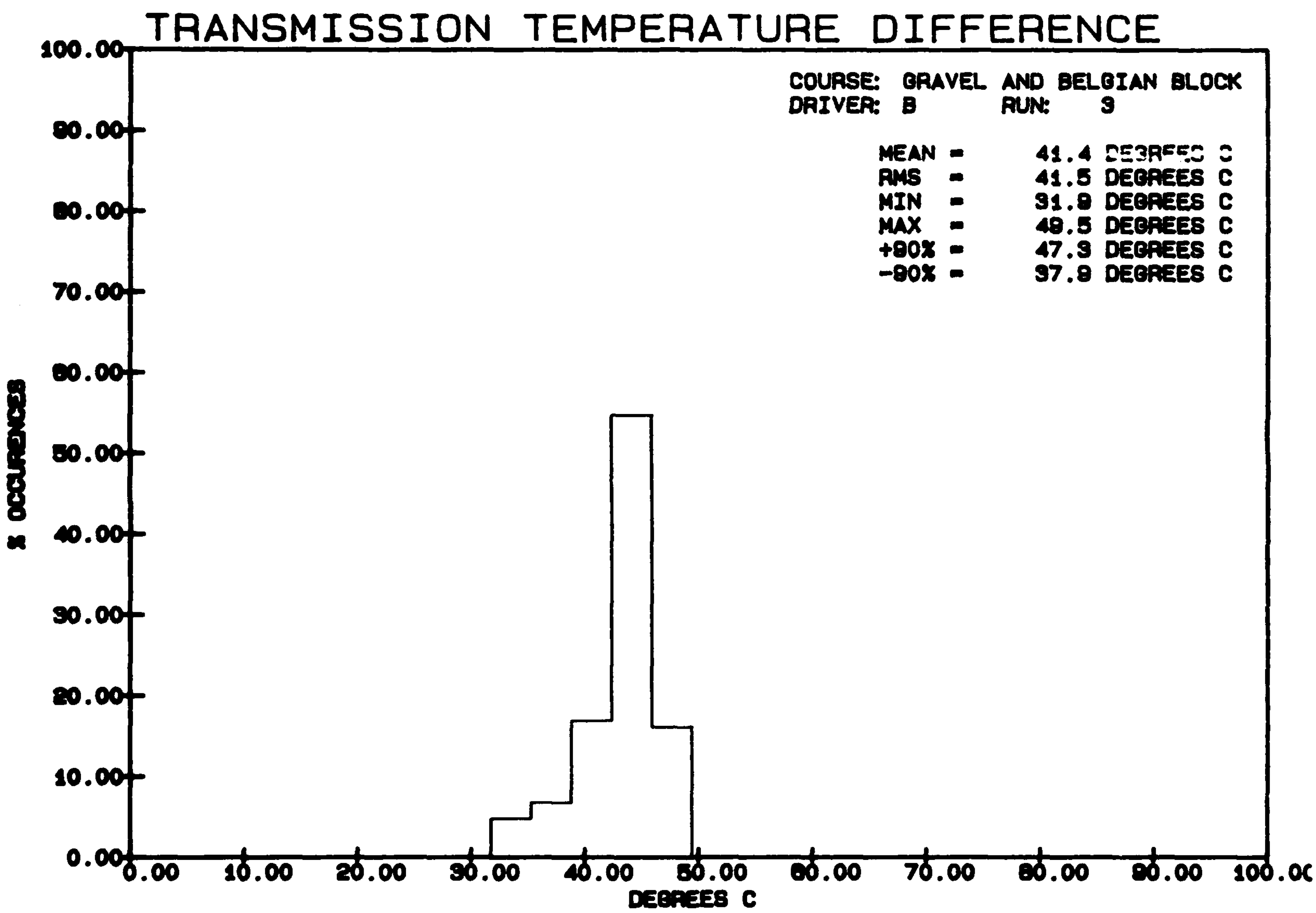

TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 3
MEAN = 41.4 DEGREES C
RMS = 41.5 DEGREES C
MIN = 31.9 DEGREES C
MAX = 49.5 DEGREES C
+90% = 47.3 DEGREES C
-90% = 37.9 DEGREES C
% OCCURENCES
DEGREES C
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00

Figure B-52

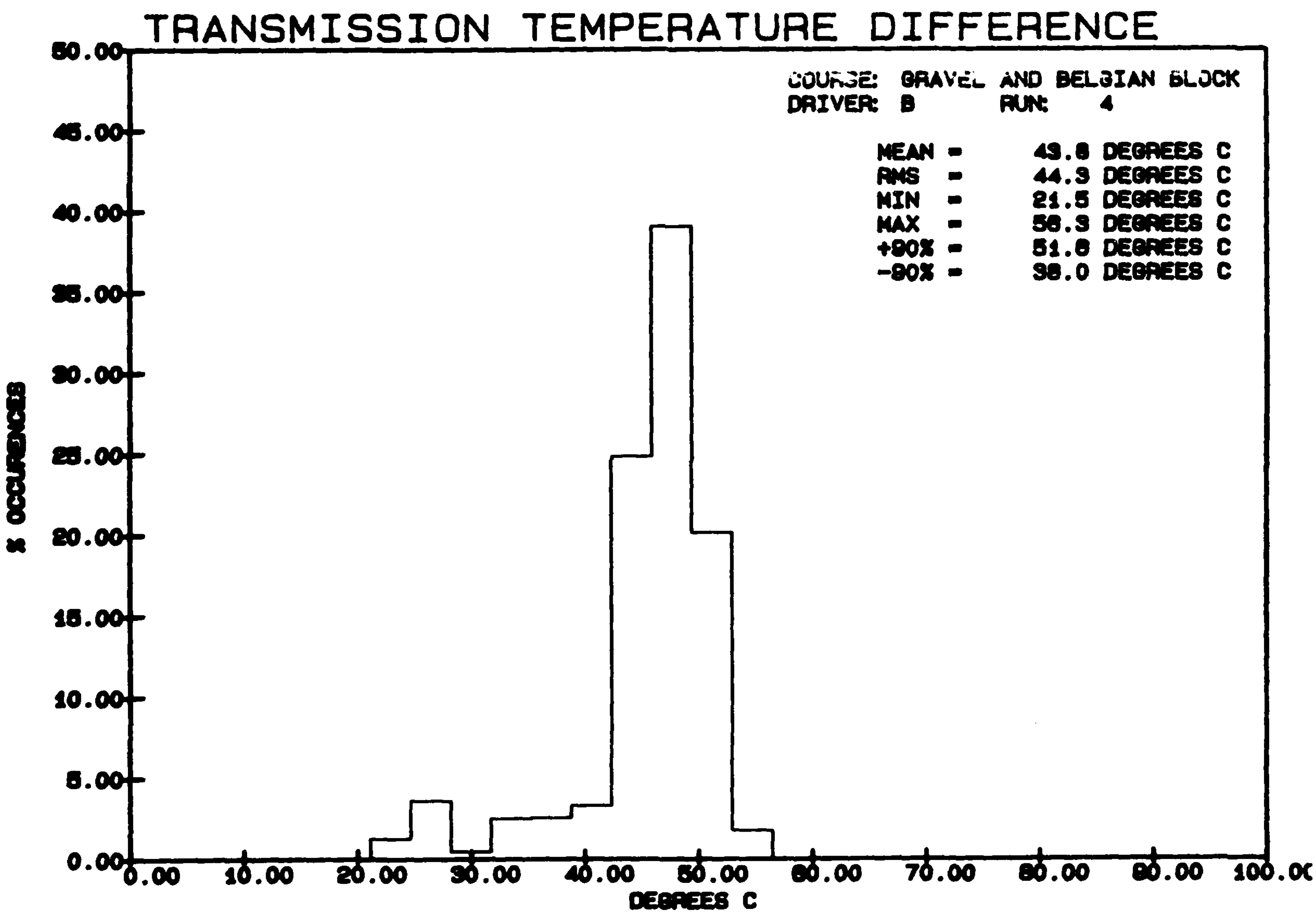

TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 4
MEAN = 43.8 DEGREES C
RMS = 44.3 DEGREES C
MIN = 21.5 DEGREES C
MAX = 56.3 DEGREES C
+90% = 51.8 DEGREES C
-90% = 38.0 DEGREES C
% OCCURENCES
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
DEGREES C

Figure B-53

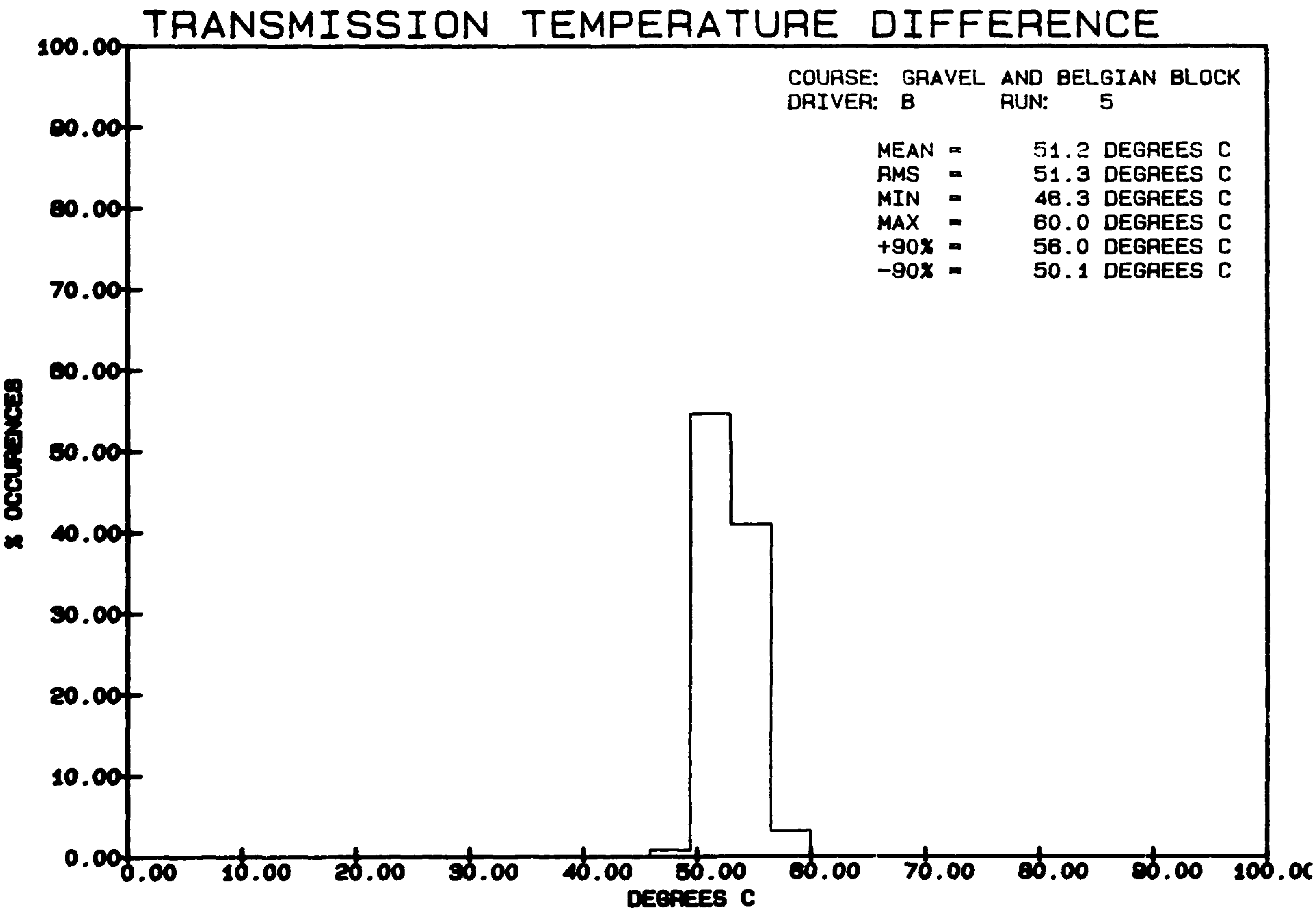
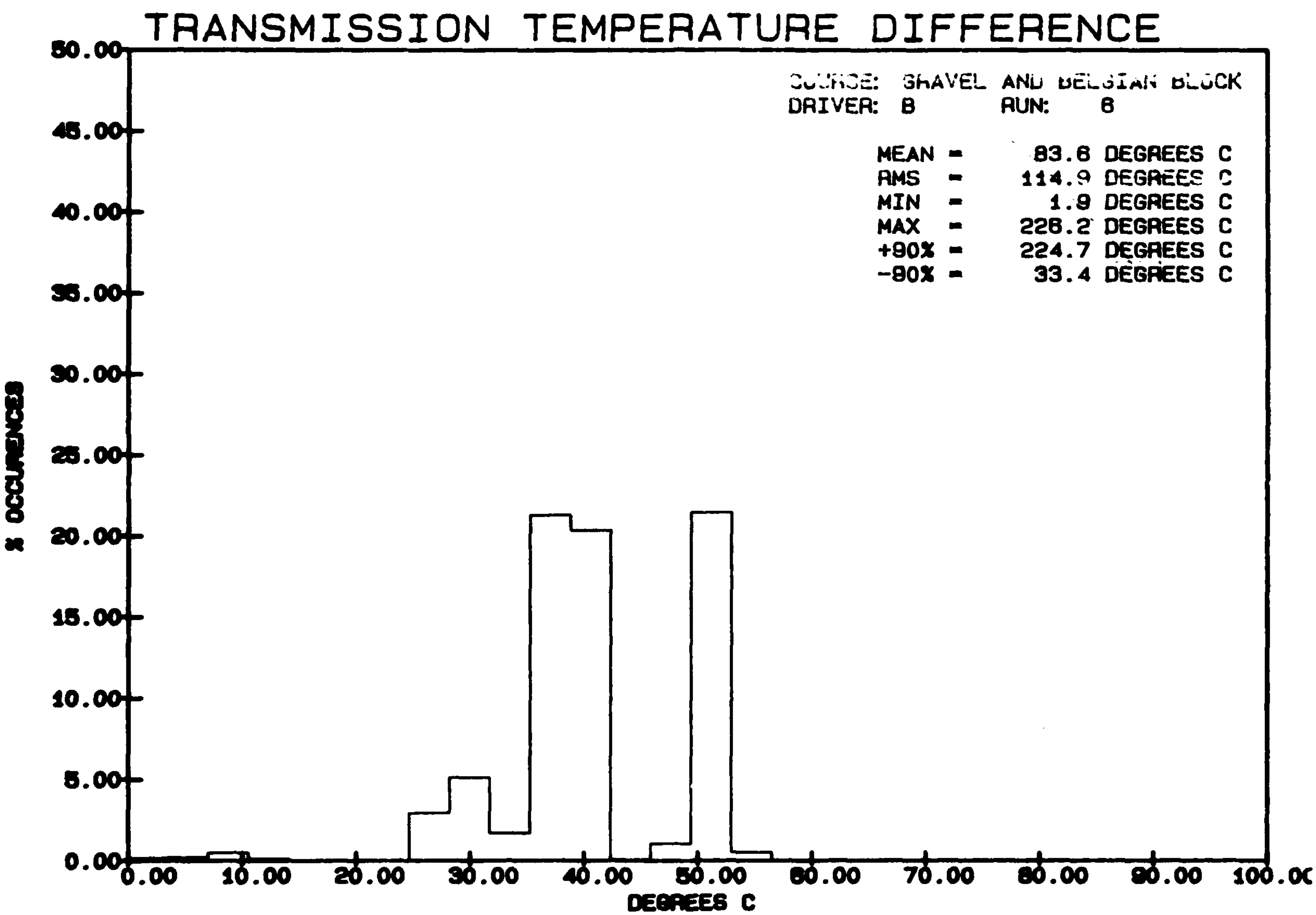

TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 5
MEAN = 51.2 DEGREES C
RMS = 51.3 DEGREES C
MIN = 48.3 DEGREES C
MAX = 60.0 DEGREES C
+90% = 56.0 DEGREES C
-90% = 50.1 DEGREES C
% OCCURENCES
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
DEGREES C

Figure B-54



TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: B RUN: 6
MEAN = 83.6 DEGREES C
RMS = 114.9 DEGREES C
MIN = 1.9 DEGREES C
MAX = 228.2 DEGREES C
+90% = 224.7 DEGREES C
-90% = 33.4 DEGREES C
% OCCURENCES
DEGREES C
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
60.00
70.00
80.00
90.00
100.00

Figure B-55

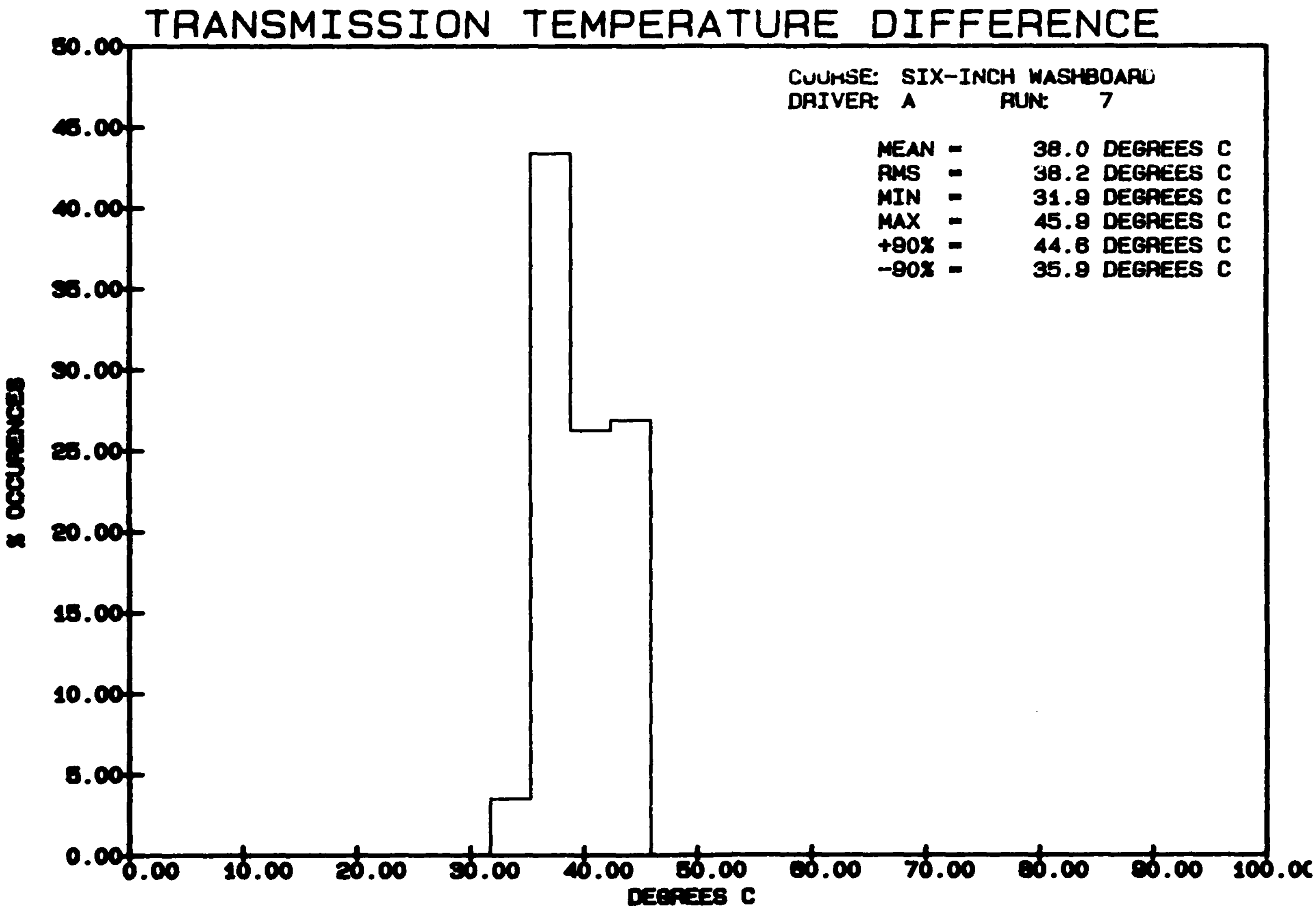

TRANSMISSION TEMPERATURE DIFFERENCE
CUURSE: SIX-INCH WASHBOARD
DRIVER: A RUN: 7
MEAN = 38.0 DEGREES C
RMS = 38.2 DEGREES C
MIN = 31.9 DEGREES C
MAX = 45.9 DEGREES C
+90% = 44.8 DEGREES C
-90% = 35.9 DEGREES C
% OCCURENCES
DEGREES C
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00

Figure B-56

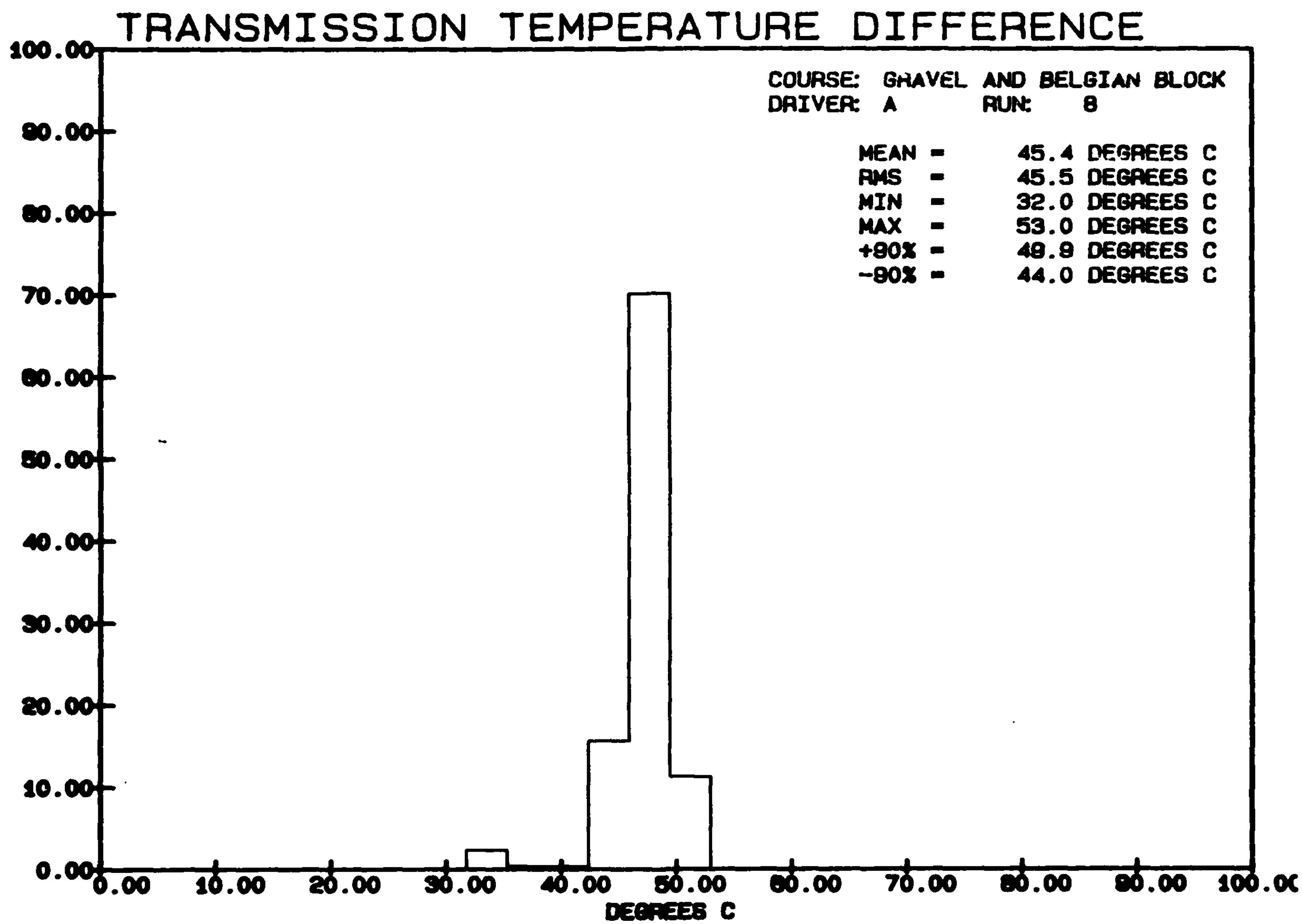

TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 8
MEAN = 45.4 DEGREES C
RMS = 45.5 DEGREES C
MIN = 32.0 DEGREES C
MAX = 53.0 DEGREES C
+90% = 48.9 DEGREES C
-90% = 44.0 DEGREES C
% OCCURENCES
DEGREES C
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00

Figure B-57

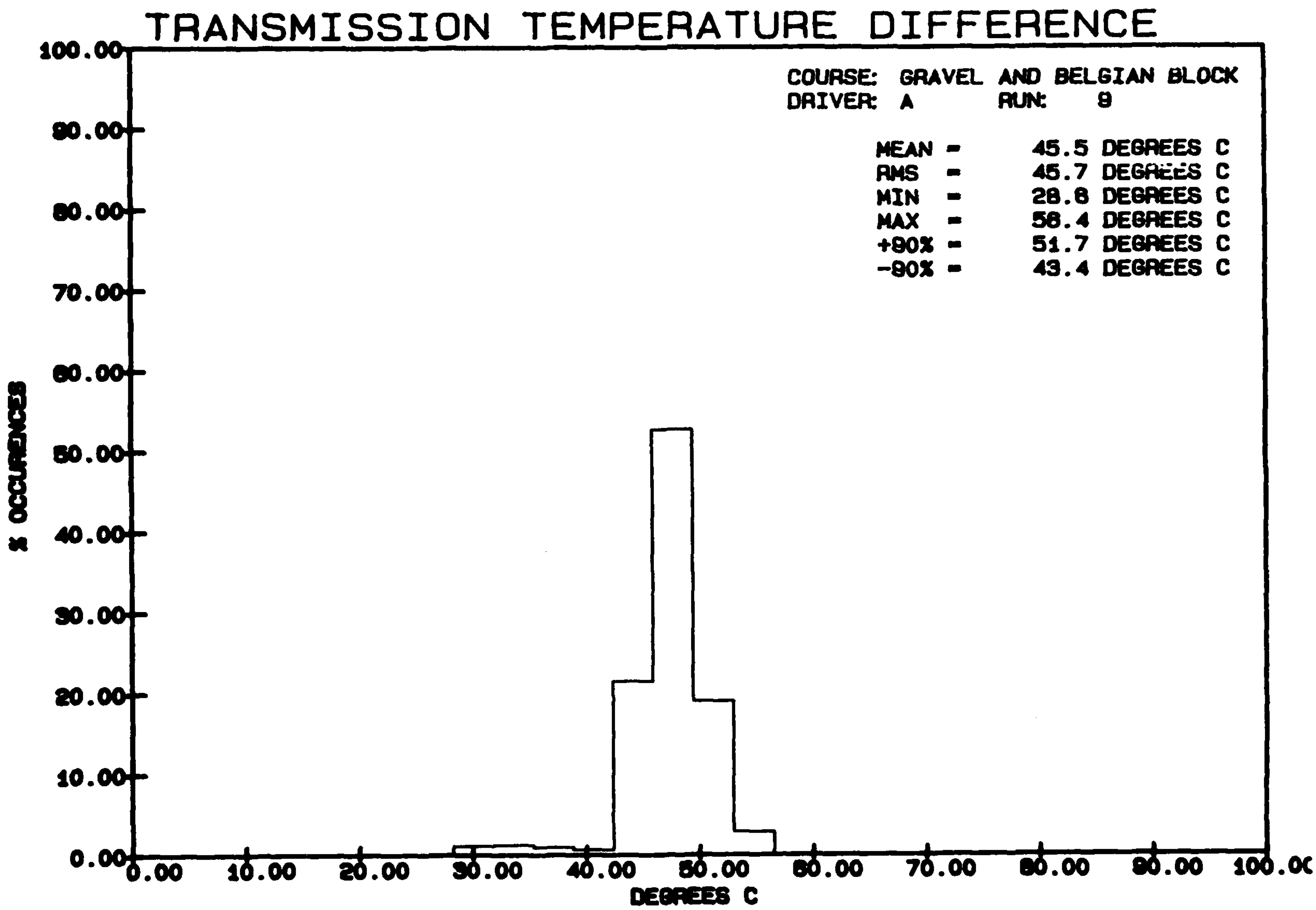

TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 9
MEAN = 45.5 DEGREES C
RMS = 45.7 DEGREES C
MIN = 28.8 DEGREES C
MAX = 56.4 DEGREES C
+90% = 51.7 DEGREES C
-90% = 43.4 DEGREES C
% OCCURENCES
DEGREES C
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00

Figure B-58

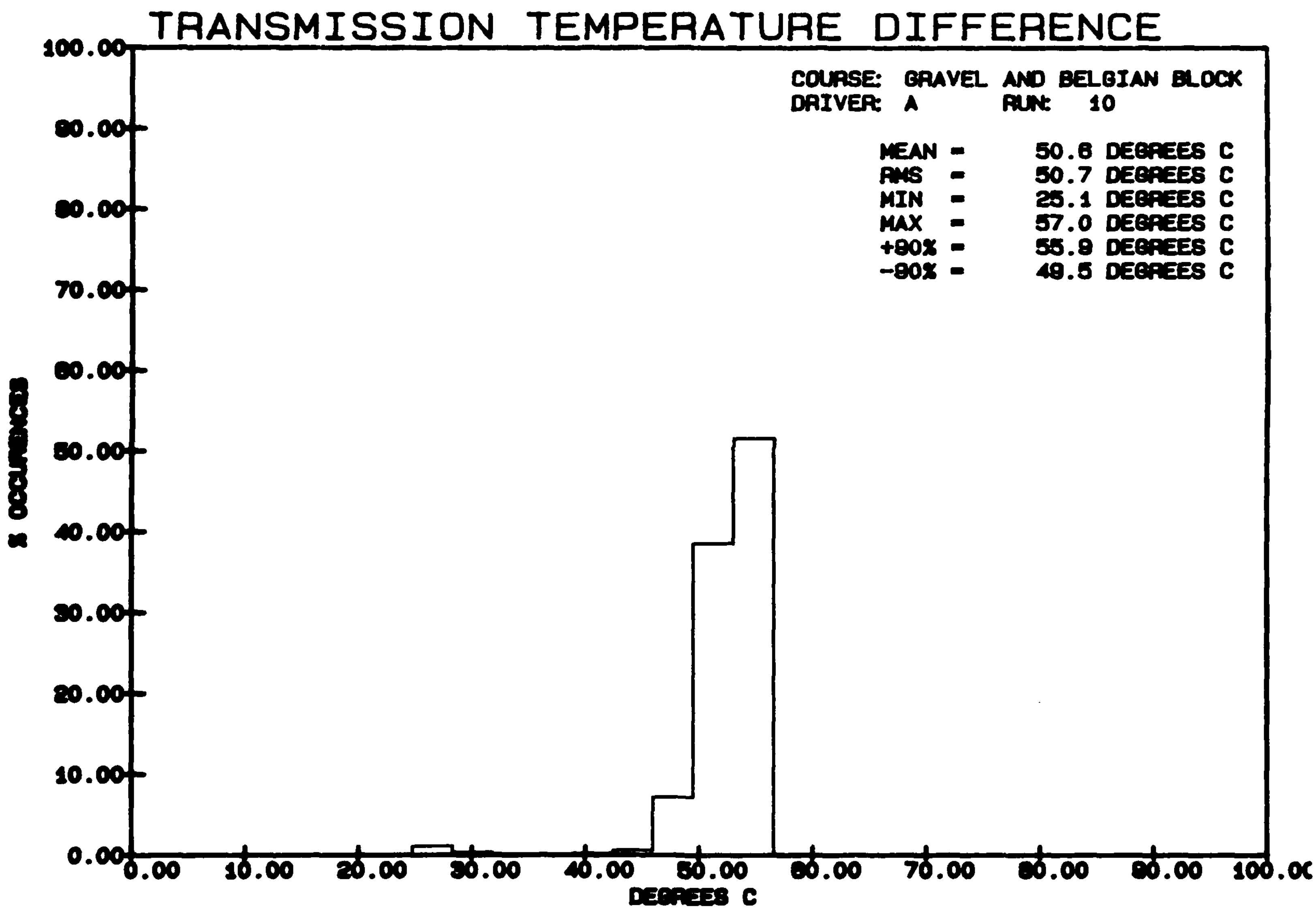

TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 10
MEAN = 50.6 DEGREES C
RMS = 50.7 DEGREES C
MIN = 25.1 DEGREES C
MAX = 57.0 DEGREES C
+90% = 55.9 DEGREES C
-90% = 49.5 DEGREES C
% OCCURRENCES
DEGREES C
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00

Figure B-59

TRANSMISSION TEMPERATURE DIFFERENCE

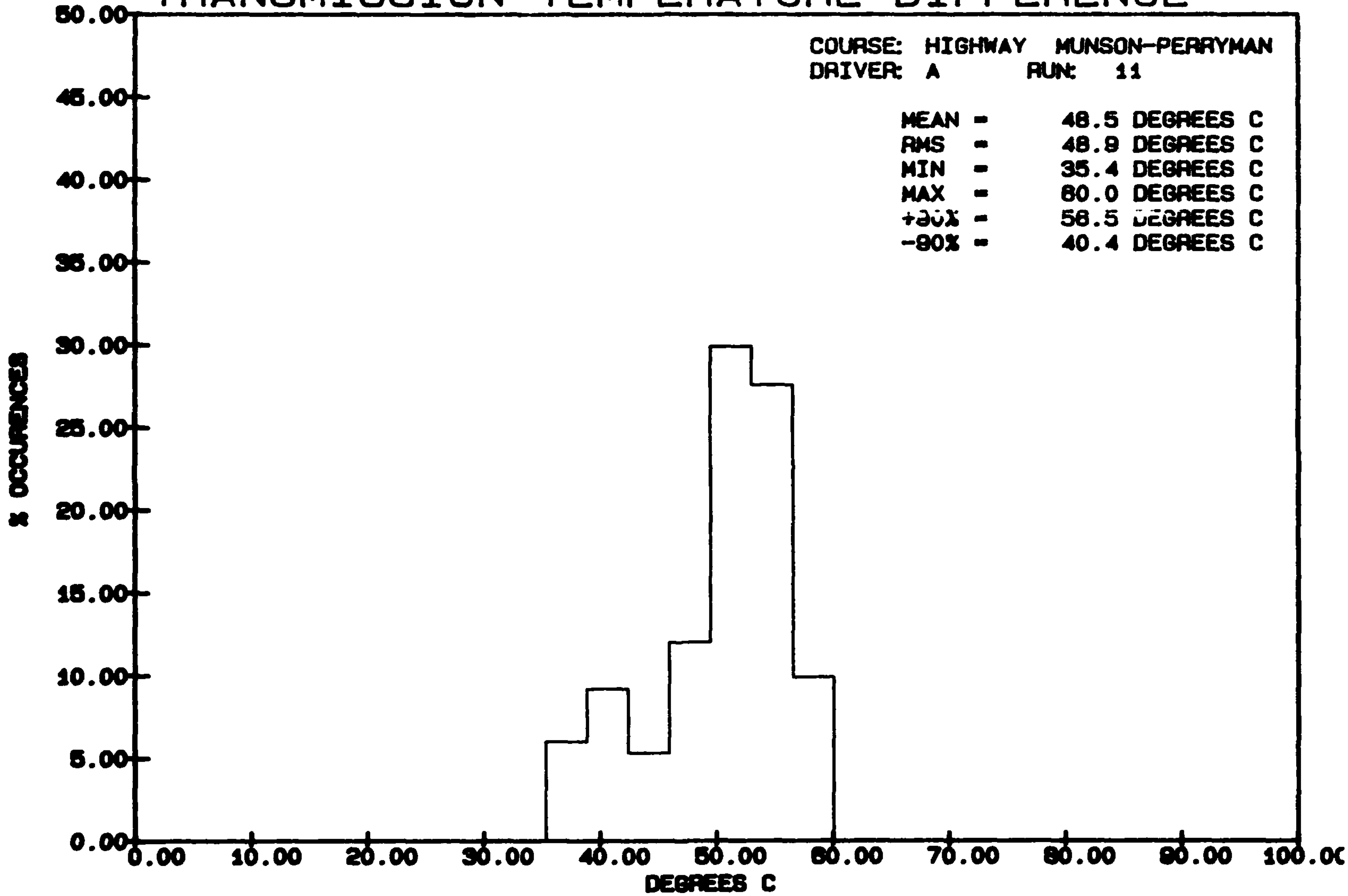


Figure B-60

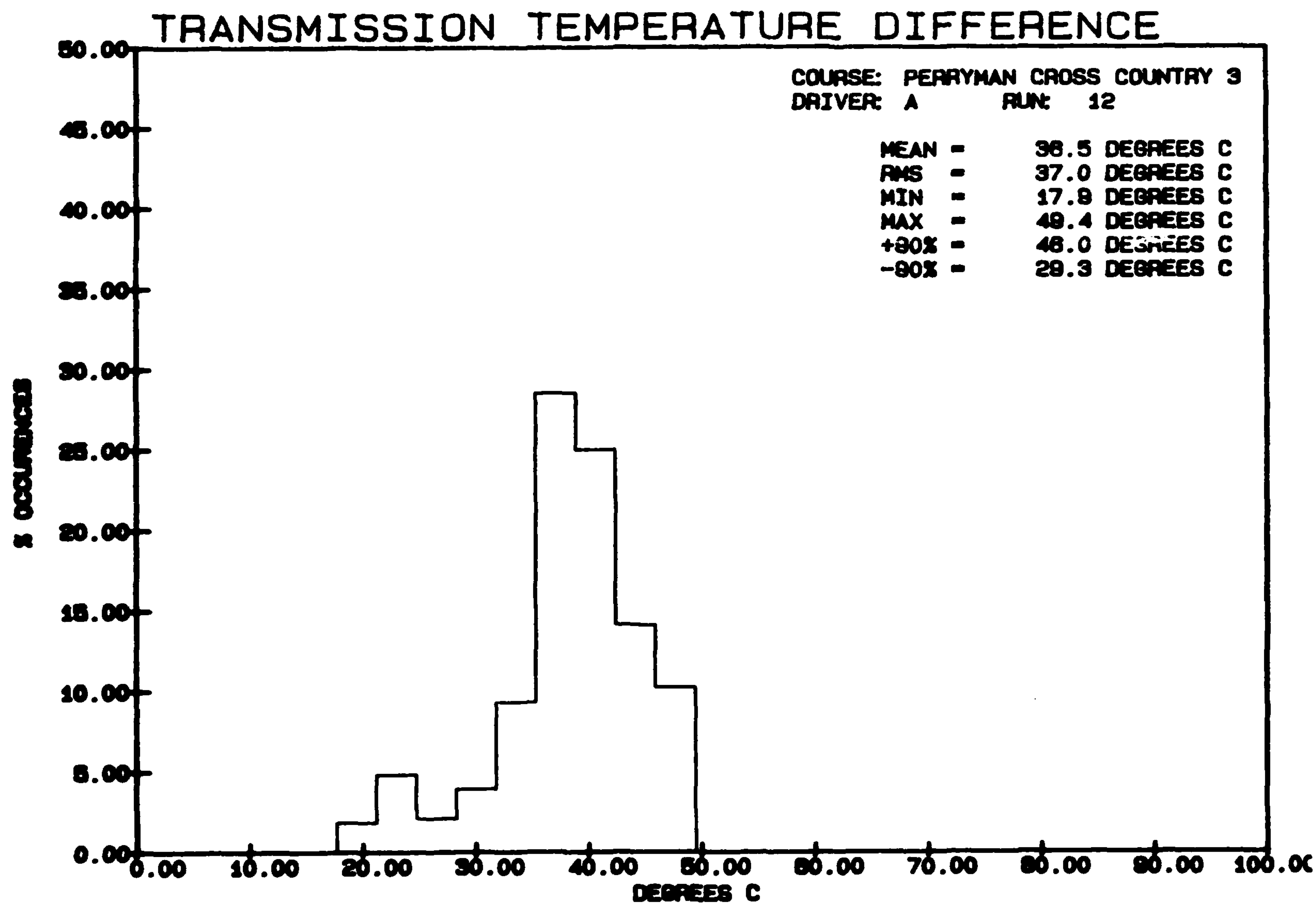
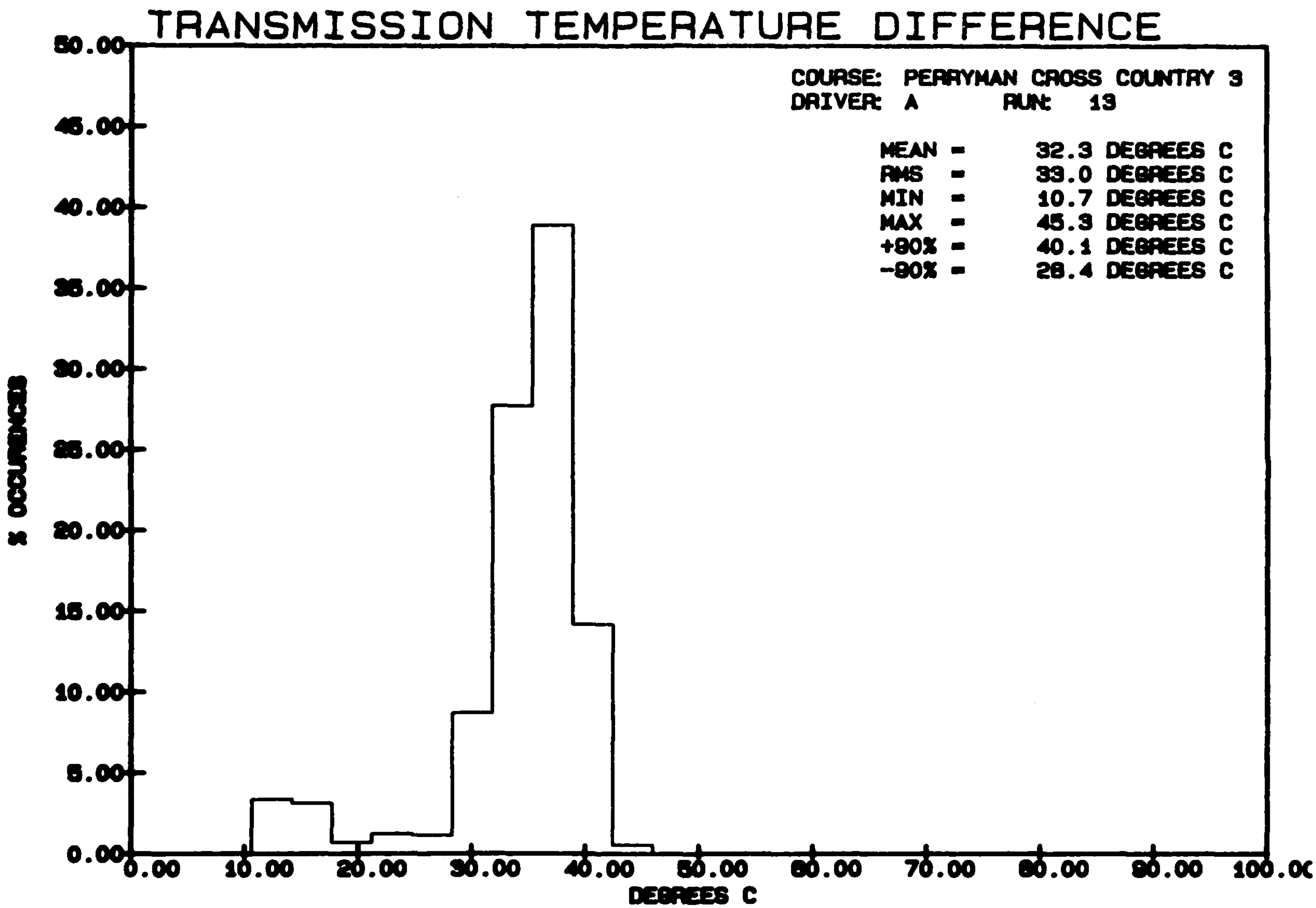

TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 12
MEAN = 36.5 DEGREES C
RMS = 37.0 DEGREES C
MIN = 17.9 DEGREES C
MAX = 49.4 DEGREES C
+90% = 46.0 DEGREES C
-90% = 29.3 DEGREES C
% OCCURRENCES
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
DEGREES C

Figure B-61



TRANSMISSION TEMPERATURE DIFFERENCE
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 13
MEAN = 32.3 DEGREES C
RMS = 33.0 DEGREES C
MIN = 10.7 DEGREES C
MAX = 45.3 DEGREES C
+90% = 40.1 DEGREES C
-90% = 28.4 DEGREES C
% OCCURRENCES
DEGREES C
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
60.00
70.00
80.00
90.00
100.00

Figure B-62

APPENDIX C - POST-TEST PROCESSED HISTOGRAMS

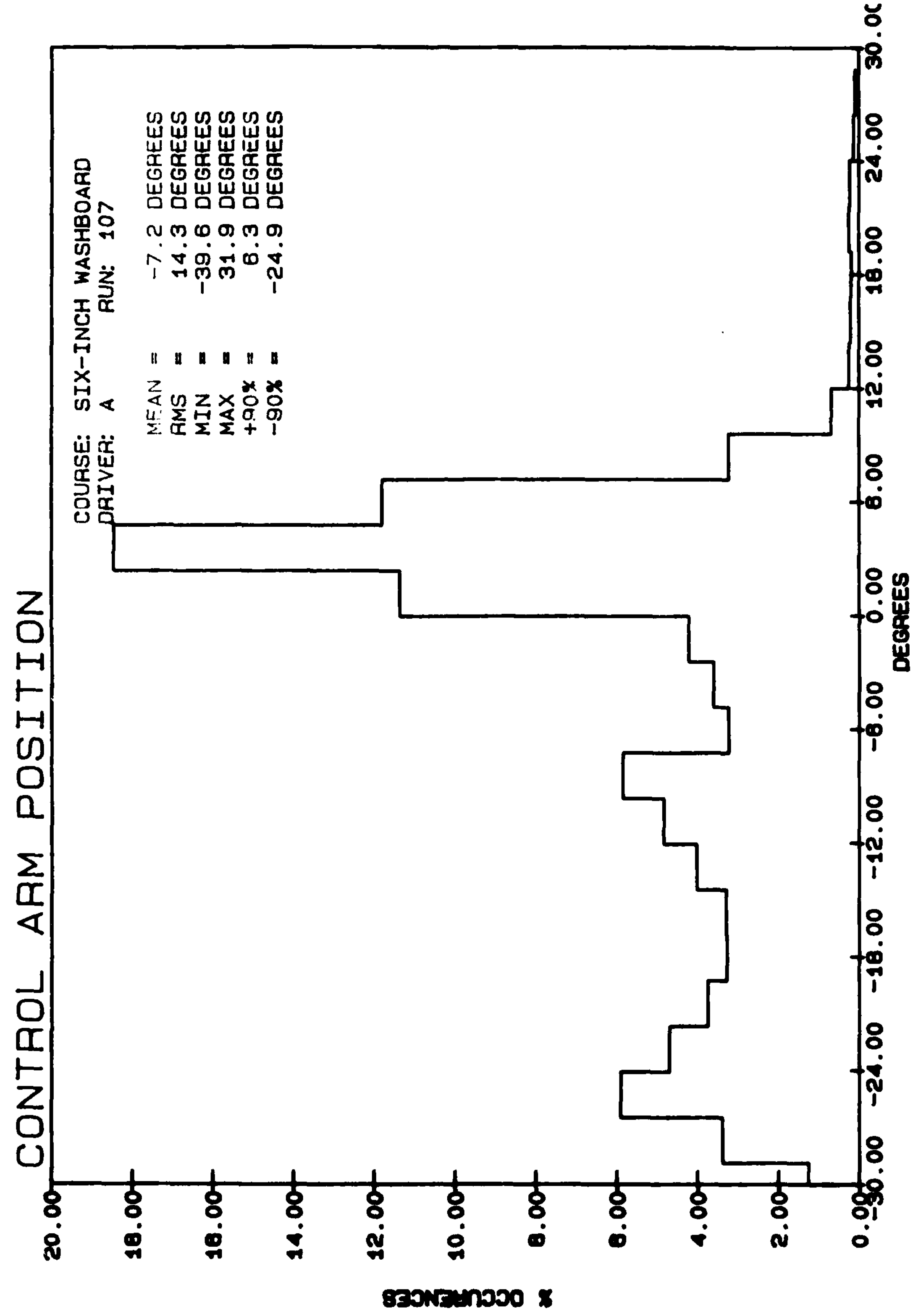


Figure C-1

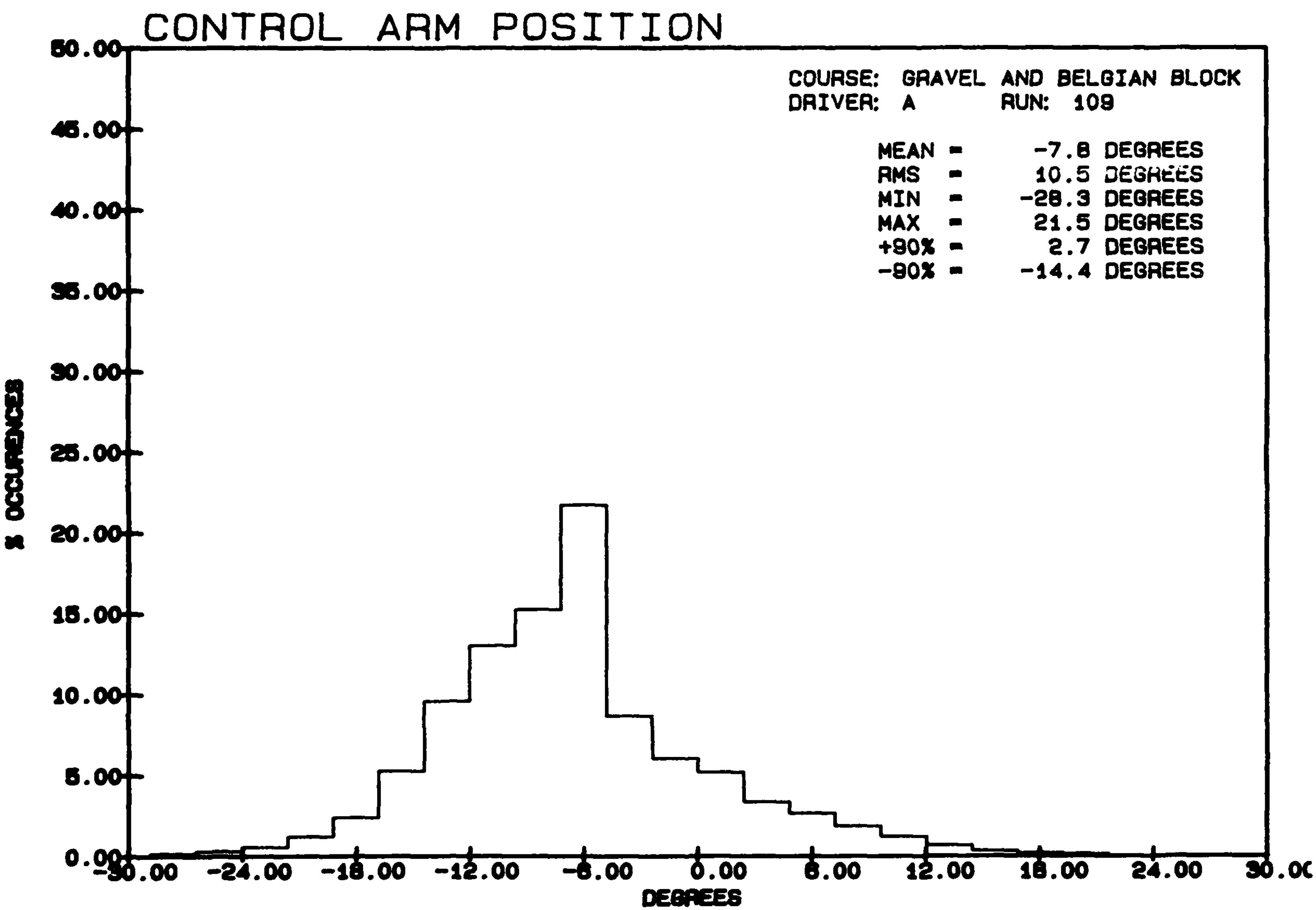

CONTROL ARM POSITION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 109
MEAN = -7.8 DEGREES
RMS = 10.5 DEGREES
MIN = -28.3 DEGREES
MAX = 21.5 DEGREES
+90% = 2.7 DEGREES
-90% = -14.4 DEGREES
% OCCURENCES
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00
DEGREES

Figure C-2

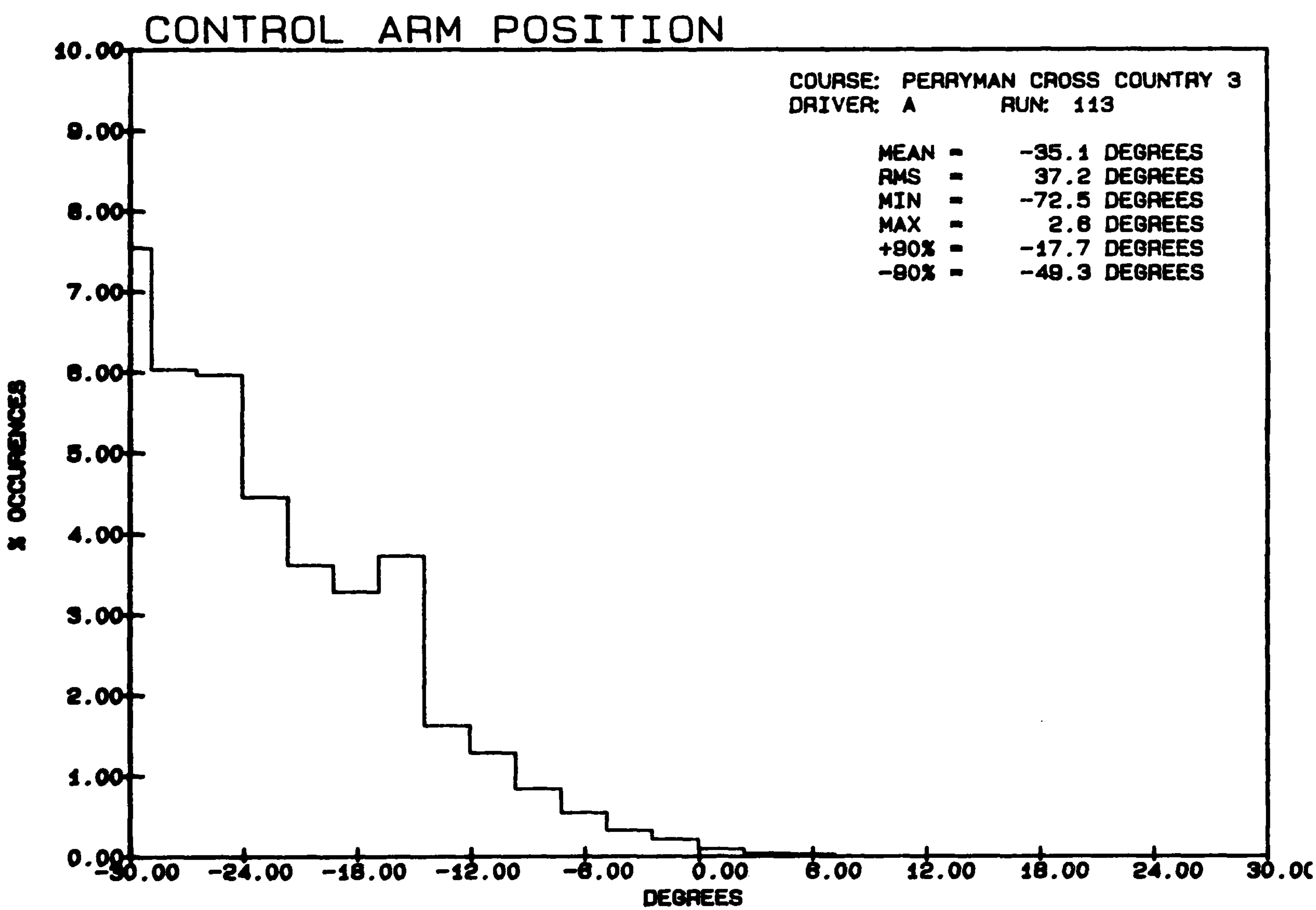

CONTROL ARM POSITION
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 113
MEAN = -35.1 DEGREES
RMS = 37.2 DEGREES
MIN = -72.5 DEGREES
MAX = 2.6 DEGREES
+90% = -17.7 DEGREES
-90% = -49.3 DEGREES
% OCCURENCES
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
-30.00
-24.00
-18.00
-12.00
-6.00
0.00
6.00
12.00
18.00
24.00
30.00
DEGREES

Figure C-3

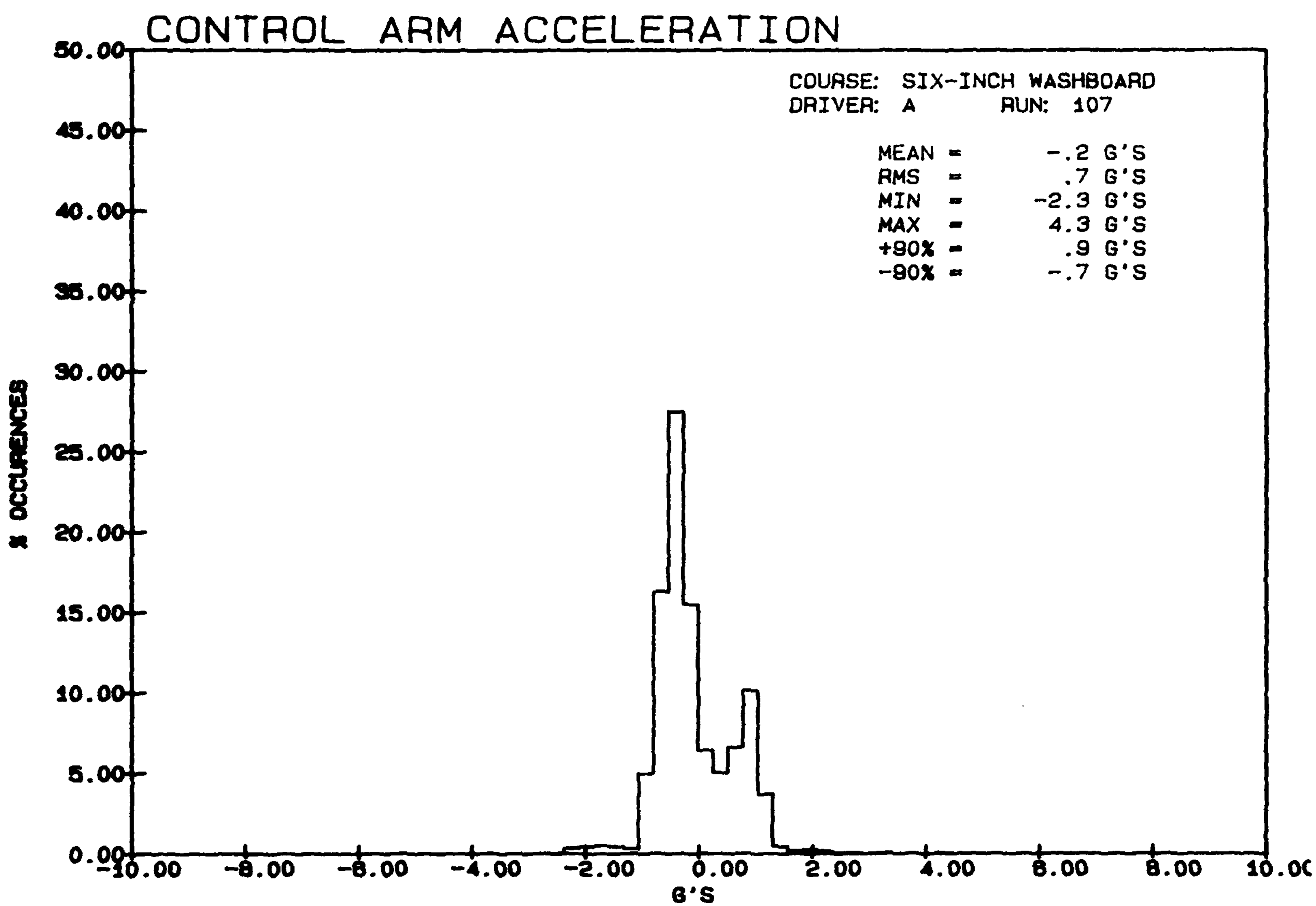

CONTROL ARM ACCELERATION
COURSE: SIX-INCH WASHBOARD
DRIVER: A RUN: 107
MEAN = -.2 G'S
RMS = .7 G'S
MIN = -2.3 G'S
MAX = 4.3 G'S
+90% = .9 G'S
-90% = -.7 G'S
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
G'S

Figure C-4

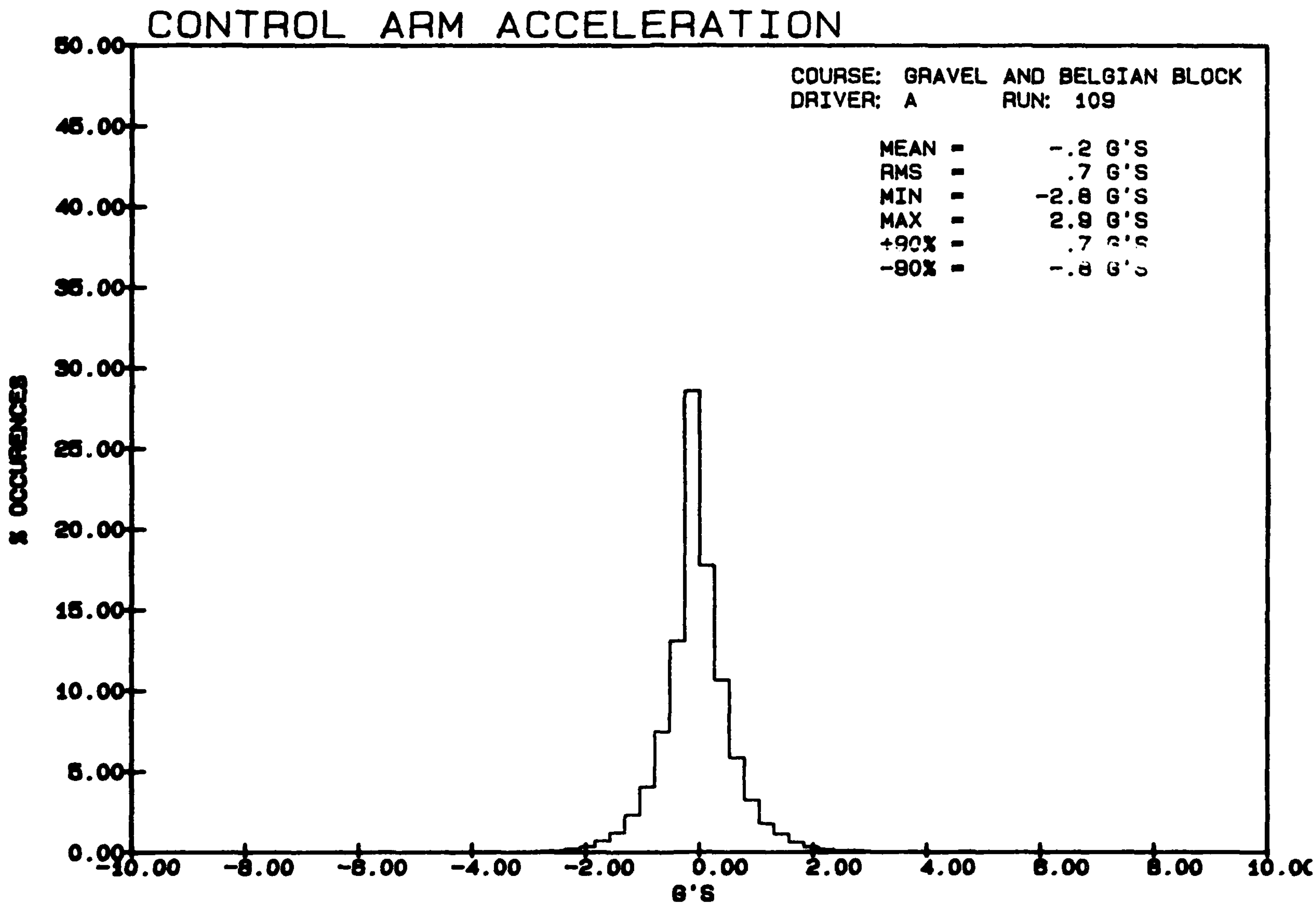

CONTROL ARM ACCELERATION
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 109
MEAN = -.2 G'S
RMS = .7 G'S
MIN = -2.8 G'S
MAX = 2.9 G'S
+90% = .7 G'S
-90% = -.8 G'S
% OCCURENCES
G'S

Figure C-5

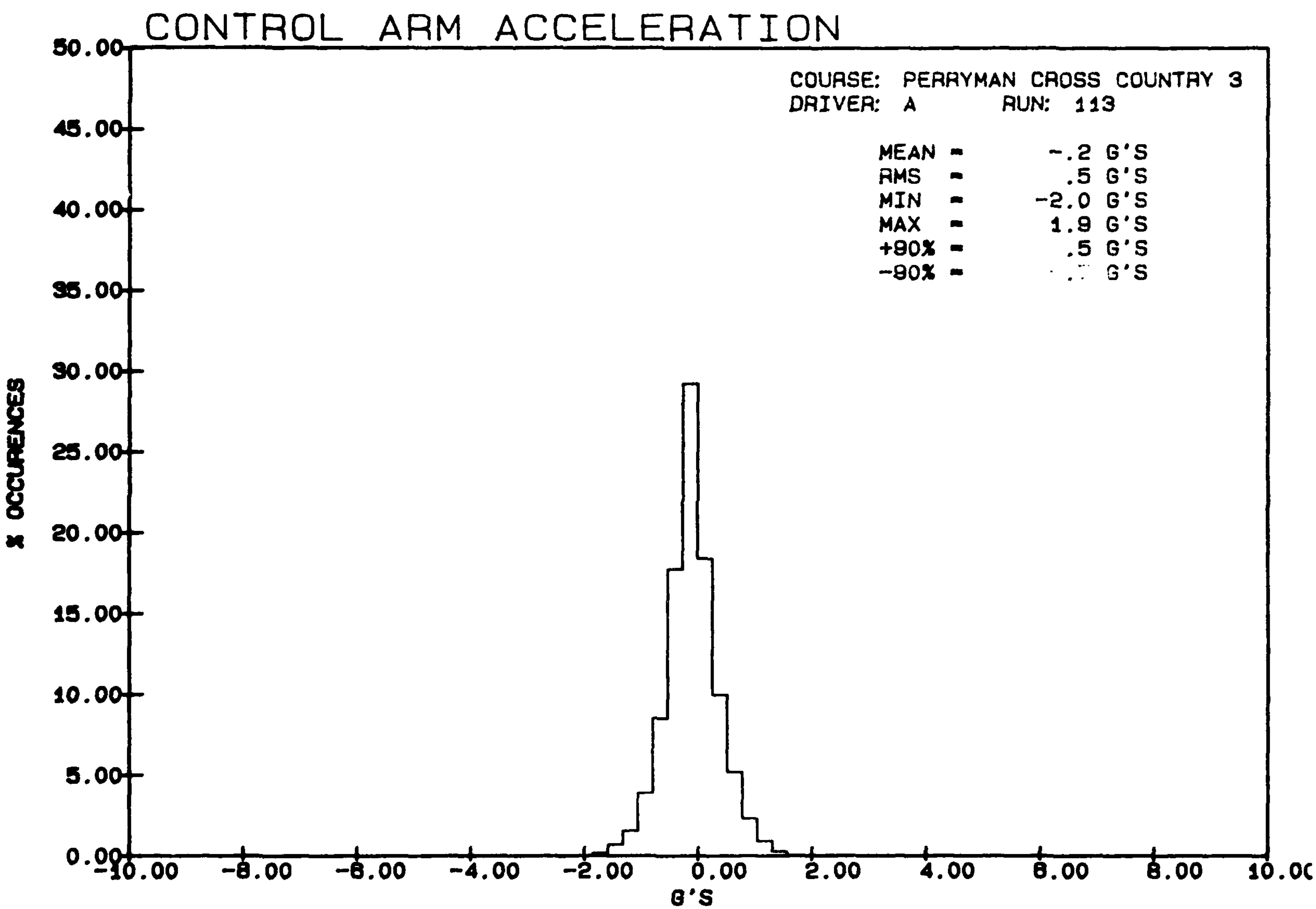

CONTROL ARM ACCELERATION
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 113
MEAN = -.2 G'S
RMS = .5 G'S
MIN = -2.0 G'S
MAX = 1.9 G'S
+90% = .5 G'S
-90% = G'S
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
-10.00
-8.00
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
8.00
10.00
G'S

Figure C-6

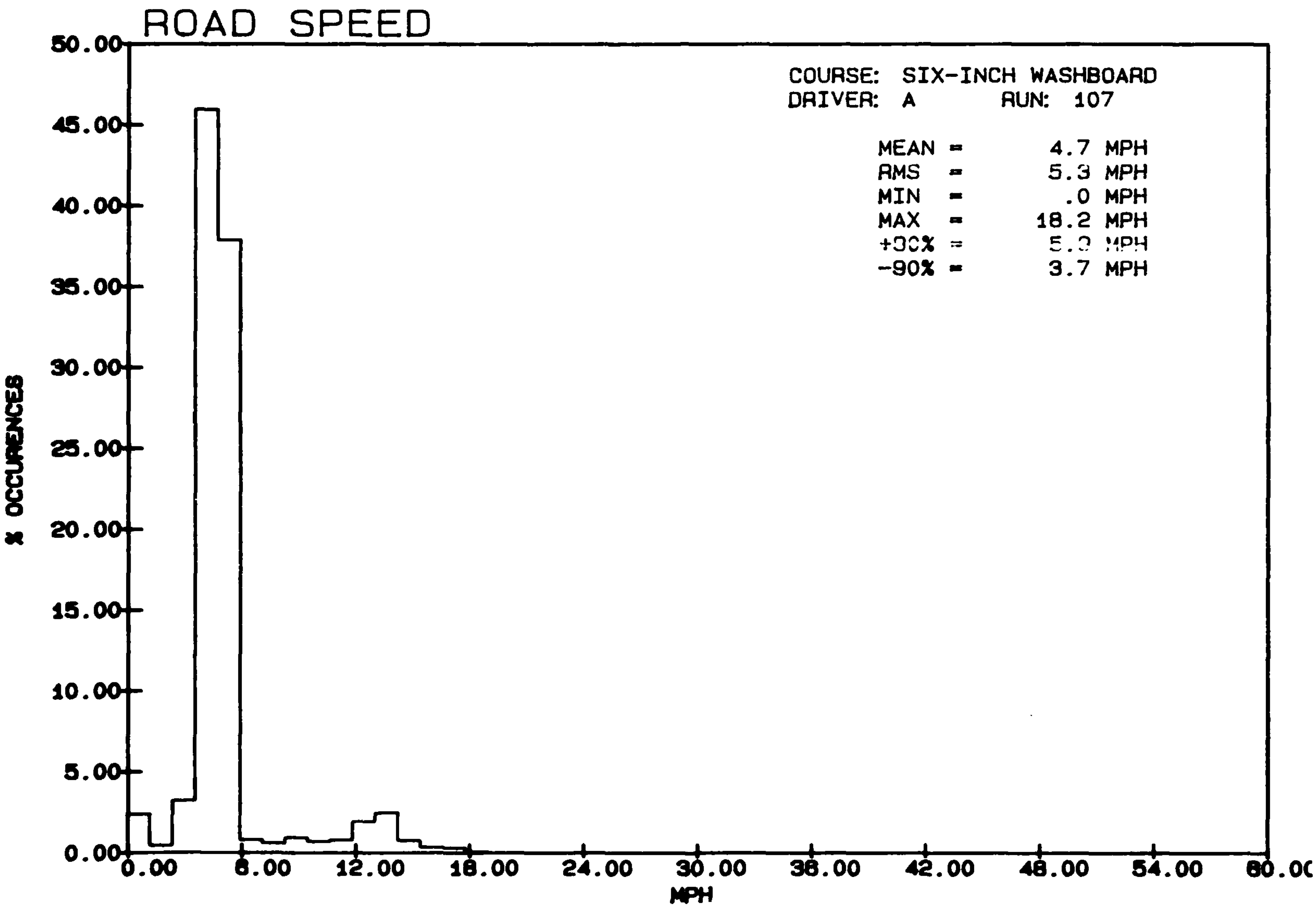

ROAD SPEED
COURSE: SIX-INCH WASHBOARD
DRIVER: A RUN: 107
MEAN = 4.7 MPH
RMS = 5.3 MPH
MIN = .0 MPH
MAX = 18.2 MPH
-90% = 3.7 MPH
% OCCURENCES
MPH
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00

Figure C-7

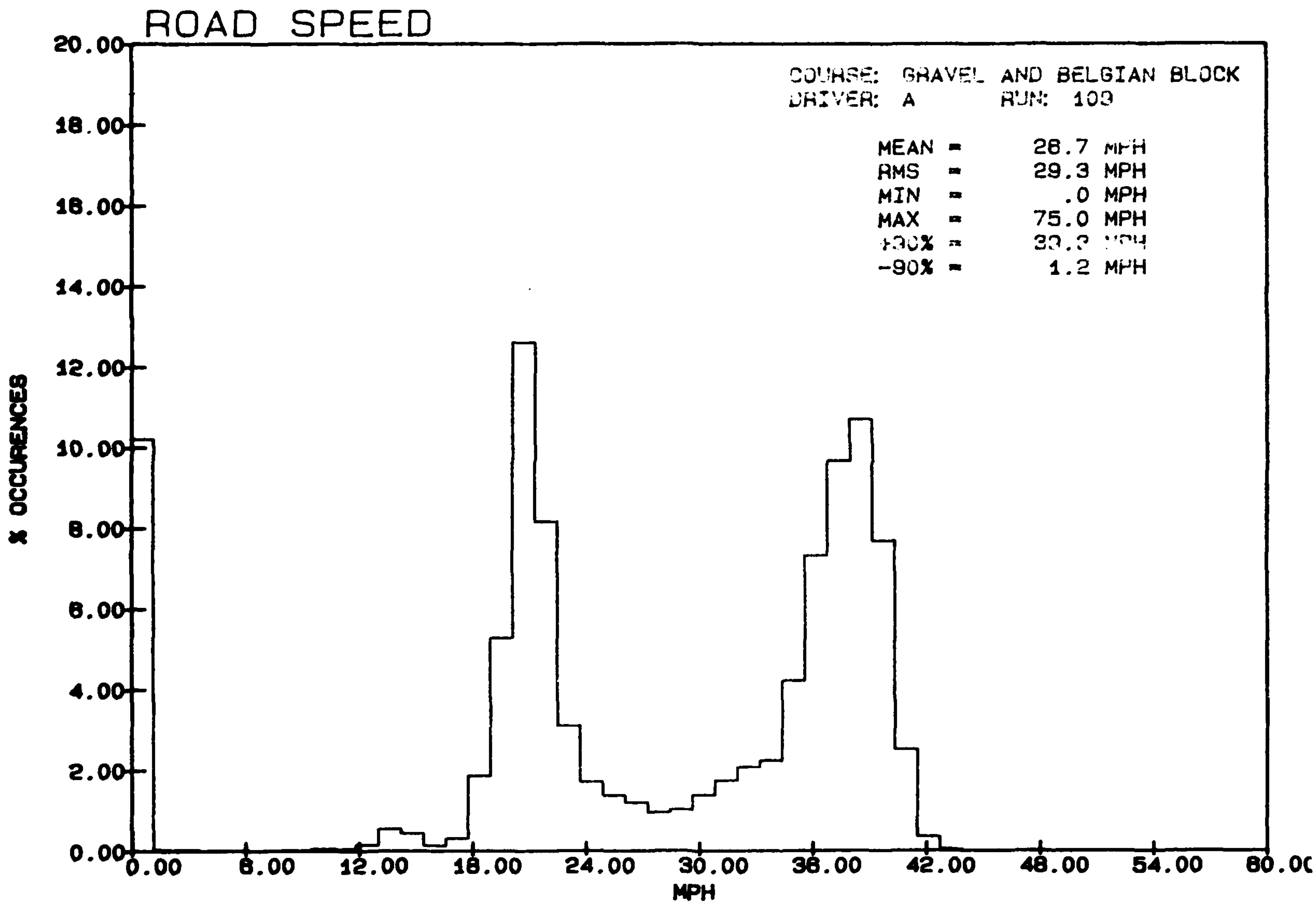

ROAD SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 109
MEAN = 28.7 MPH
RMS = 29.3 MPH
MIN = .0 MPH
MAX = 75.0 MPH
-90% = 1.2 MPH
% OCCURENCES
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00
60.00
MPH

Figure C-8

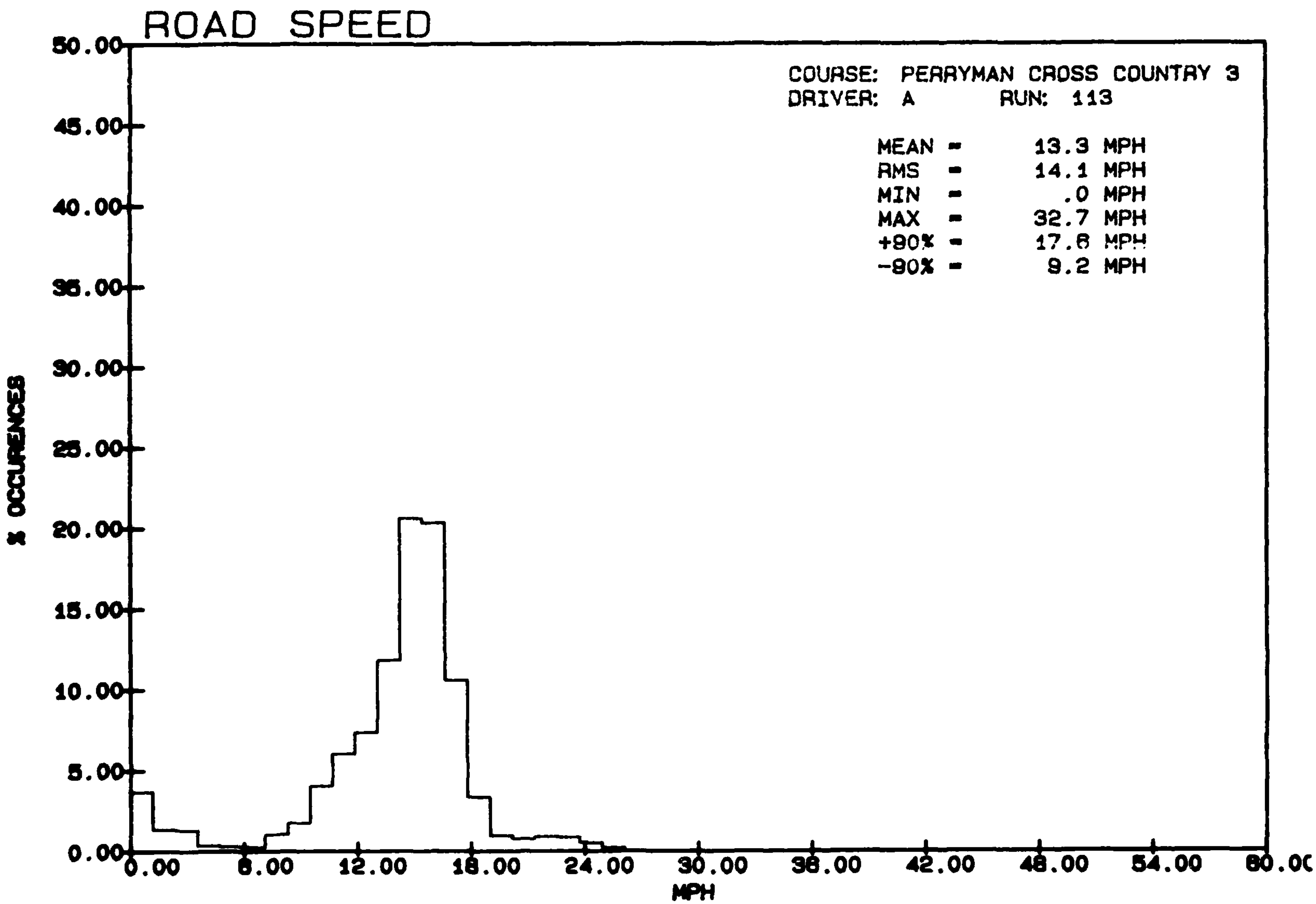

ROAD SPEED
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 113
MEAN = 13.3 MPH
RMS = 14.1 MPH
MIN = .0 MPH
MAX = 32.7 MPH
+90% = 17.6 MPH
-90% = 9.2 MPH
% OCCURENCES
MPH
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
6.00
12.00
18.00
24.00
30.00
36.00
42.00
48.00
54.00

Figure C-9

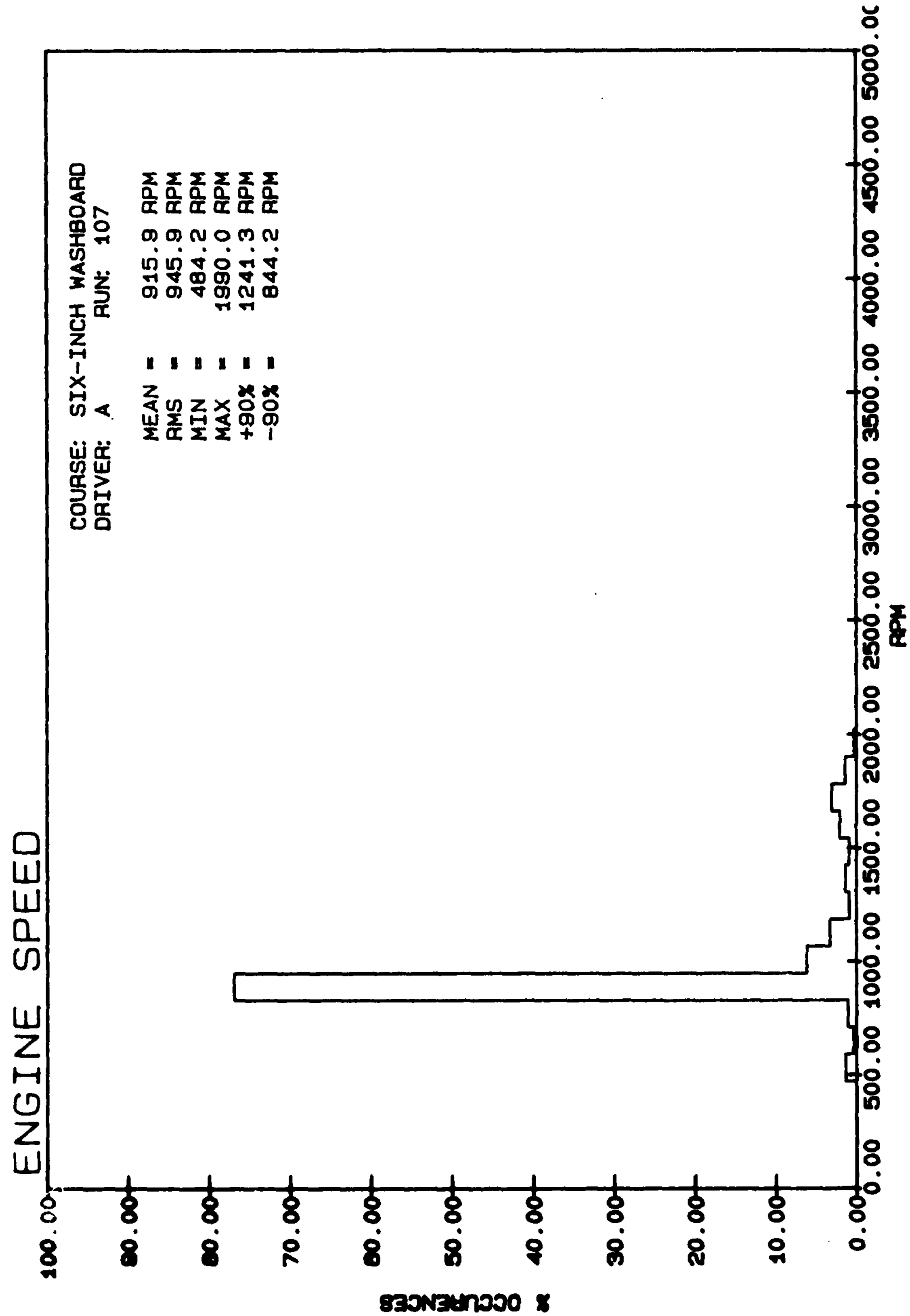

ENGINE SPEED
COURSE: SIX-INCH WASHBOARD
DRIVER: A RUN: 107
MEAN = 915.9 RPM
RMS = 945.9 RPM
MIN = 484.2 RPM
MAX = 1990.0 RPM
+90% = 1241.3 RPM
-90% = 844.2 RPM
% OCCURENCES
RPM
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00

Figure C-10

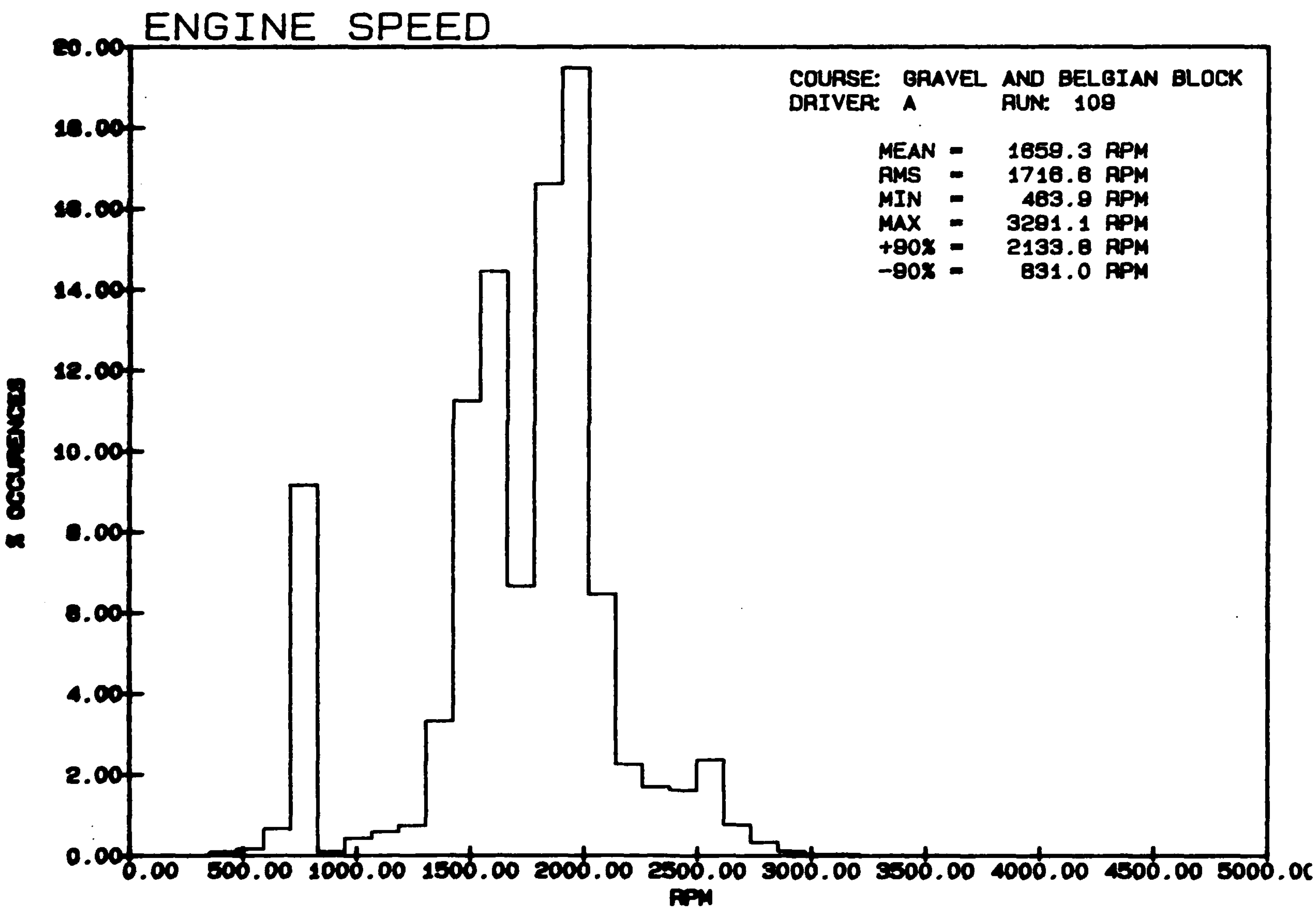

ENGINE SPEED
COURSE: GRAVEL AND BELGIAN BLOCK
DRIVER: A RUN: 109
MEAN = 1659.3 RPM
RMS = 1716.8 RPM
MIN = 463.9 RPM
MAX = 3291.1 RPM
+90% = 2133.8 RPM
-90% = 831.0 RPM
% OCCURENCES
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00
RPM

Figure C-11

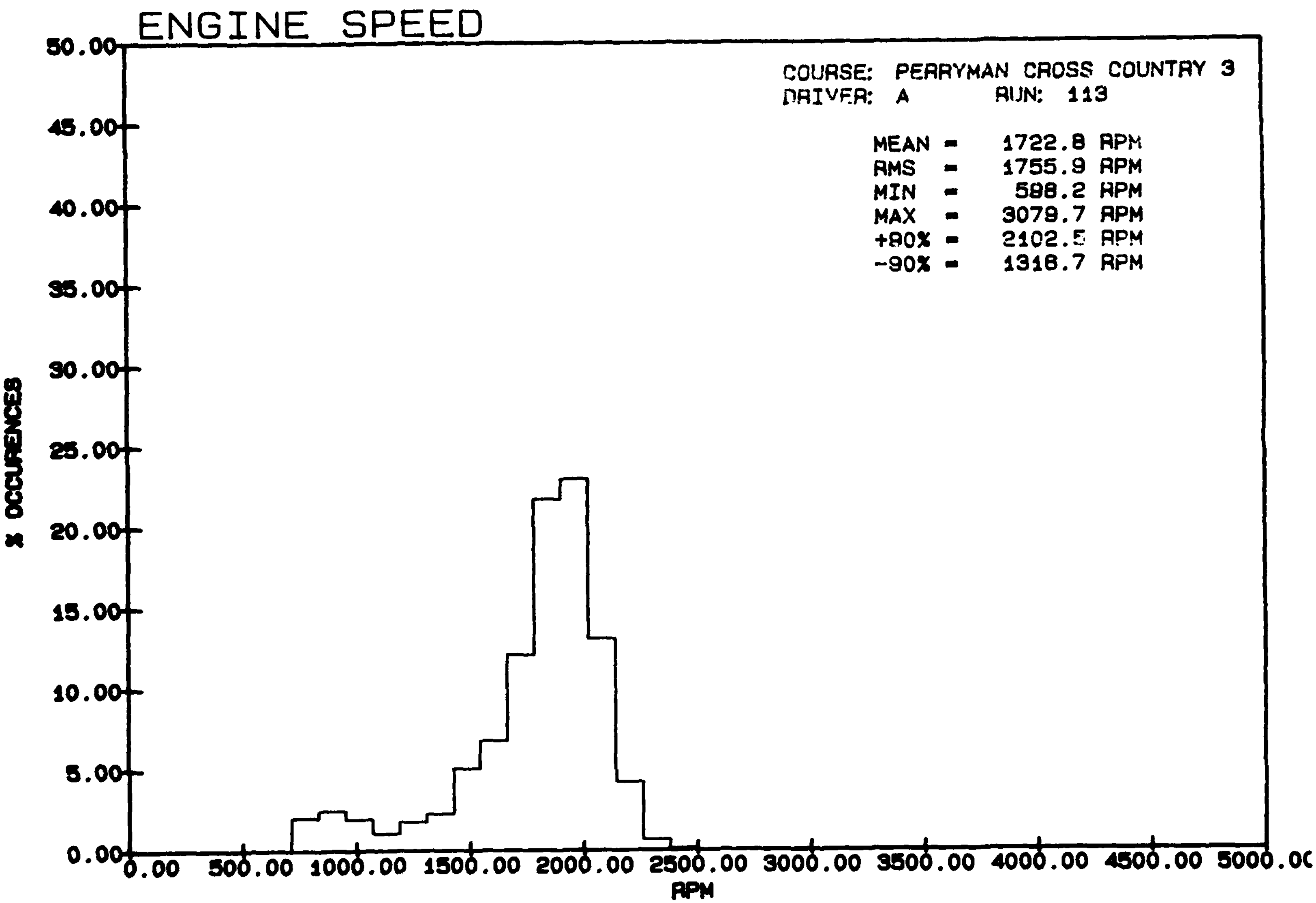

ENGINE SPEED
COURSE: PERRYMAN CROSS COUNTRY 3
DRIVER: A RUN: 113
MEAN = 1722.8 RPM
RMS = 1755.9 RPM
MIN = 598.2 RPM
MAX = 3079.7 RPM
+90% = 2102.5 RPM
-90% = 1316.7 RPM
% OCCURENCES
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.00
500.00
1000.00
1500.00
2000.00
2500.00
3000.00
3500.00
4000.00
4500.00
5000.00
RPM

Figure C-12

APPENDIX D - COMPARISON OF HISTOGRAM STATISTICS

TABLE D-1.

	Control Arm Position (deg)			
Run	Mean	Ratio (VPR/PCM)	RMS	Ratio (VPR/PCM)
107 (PCM)	-7.2	0.903	14.3	0.895
7 (VPR)	-6.5		12.	
109 (PCM)	-7.8	.897	10.5	.943
9 (VPR)	-7.0		9.9	

Average ratio: 0.910

TABLE D-2.

	Control Arm Position (deg)			
Run	Range (+ to -)	Ratio (VPR/PCM)	80% (+90% to -90%)	Ratio (VPR/PCM)
107 (PCM)	71.5	0.978	31.2	0.942
7 (VPR)	69.9		29.4	
109 (PCM)	49.8	1.000	17.1	1.006
9 (VPR)	49.8		17.2	

Average ratio: 0.982

TABLE D-3.

Run	Control Arm Acceleration (g's) Mean	Ratio (VPR/PCM)	RMS	Ratio (VPR/PCM)
107 (PCM)	-0.2	[a]0.5	0.7	0.857
7 (VPR)	- .1		.6	
109 (PCM)	- .2	[a]0.5	.7	0.857
9 (VPR)	- .1		.6	
113 (PCM)	- .2	[a]0.5	.5	1.000
13 (VPR)	- .1		.5	

Average ratio: 0.905

[a]Values not used due to lack of resolution.

TABLE D-4.

Run	Control Arm Acceleration (g's) Range (+ to -)	Ratio (VPR/PCM)	80% (+90% to -90%)	Ratio (VPR/PCM)
107 (PCM)	6.6	0.924	1.6	0.938
7 (VPR)	6.1		1.5	
109 (PCM)	5.7	0.965	1.5	1.000
9 (VPR)	5.5		1.5	
113 (PCM)	3.9	1.000	1.2	1.083
13 (VPR)	3.9		1.3	

Average ratio: 0.985

TABLE D-5.

Run	Road Speed (mph) Mean	Ratio (VPR/PCM)	RMS	Ratio (VPR/PCM)
1 (PCM)	4.7	0.830	5.3	0.907
7 (VPR)	3.9		4.9	
2 (PCM)	26.7	0.951	29.3	0.976
9 (VPR)	25.4		28.6	
3 (PCM)	13.3	1.053	14.1	1.078
13 (VPR)	14.0		15.2	

Average ratio: 0.969

TABLE D-6.

Run	Road Speed (mph) Range (+ to -)	Ratio (VPR/PCM)	80% (+90% to -90%)	Ratio (VPR/PCM)
1 (PCM)	18.2	0.896	2.2	[a]2.455
7 (VPR)	16.3		5.4	
2 (PCM)	Noise	--	38.1	1.000
9 (VPR)	42.2		38.1	
3 (PCM)	32.7	0.963	8.4	[a]2.036
13 (VPR)	31.5		17.1	

Average ratio: 0.953

[a]Not including these values.

TABLE D-7.

Run	Engine Speed (rpm) Mean	Ratio (VPR/PCM)	RMS	Ratio (VPR/PCM)
1 (PCM)	916	0.974	946	0.980
7 (VPR)	892		927	
2 (PCM)	1659	.989	1717	1.002
9 (VPR)	1640		1720	

Average ratio: 0.986

TABLE D-8.

Run	Engine Speed (rpm) Range (+ to -)	Ratio (VPR/PCM)	80% (+90% to -90%)	Ratio (VPR/PCM)
1 (PCM)	1506	1.227	397	0.829
7 (VPR)	1848		329	
2 (PCM)	2827	1.054	1303	1.104
9 (VPR)	2981		1438	

Average ratio: 1.054

APPENDIX E - TACHOGRAPH

The tachograph is a device which records road speed and engine rpm over a 24 hour period. The recording media is a pen and ink circular chart recorder. The circular chart used is approximately 6 inches in diameter, which translates into 3/4 inch per hour and causes difficulty in reading and yields low resolution.

The VPR incorporates the tachograph function. The engine and road speed are both processed in real time to determine the average, maximum, and minimum values which occur in any 1 minute time slice. At the end of each minute these data are stored in memory.

Figure E-1 is the Pascal implementation of the VPR's tachograph task. The tachograph task executes five times each second and saves its results after processing 300 samples. Figures E-2 through E-7 are the tachograph records collected during the HMMWV/VPR integration testing. The correspondence between the tachograph data and the histograms in Appendix B are in Table E-1.

TABLE E-1. TACHOGRAPH - HISTOGRAM RELATIONSHIPS

Figure No.	Run No.
E-2	NA
E-3	NA
E-4	1, 2, 3
E-5	4, 5, 6
E-6	7, 8, 9, 10
E-7	11, 12, 13

```
 "Z80"
OPTIMIZE ON
EXTENSIONS ON
SEPARATE ON

 PROGRAM TACHOGRAPH;

 TYPE
 SPD_ARY =       ARRAY[0..719] OF BYTE;

 VAR
EXTVAR ON
 DATA_BUF:       ARRAY[0..24] OF INTEGER;
 RET_CODE:       INTEGER;

GLOBVAR ON
 SPD_CH:         INTEGER;
 RPM_CH:         INTEGER;
 SPD_SF:         INTEGER;
 RPM_SF:         INTEGER;
 ACCUM:          INTEGER;
 T_INDEX:        INTEGER;
 AVG_SPD:        SPD_ARY;
 MAX_SPD:        SPD_ARY;
 MIN_SPD:        SPD_ARY;
 AVG_RPM:        SPD_ARY;
 MAX_RPM:        SPD_ARY;
 MIN_RPM:        SPD_ARY;
 MSG_TAC:        INTEGER;

GLOBVAR OFF
 INDEX:          INTEGER;
 LCL_AVG_SPD:    INTEGER;
 LCL_MAX_SPD:    INTEGER;
 LCL_MIN_SPD:    INTEGER;
 LCL_AVG_RPM:    INTEGER;
 LCL_MAX_RPM:    INTEGER;
 LCL_MIN_RPM:    INTEGER;
 DATA:           INTEGER;

 CONST
 TMOUT     =     0;
 MAX_INDEX =     719;

 PROCEDURE SC_TDELETE(CMD_CODE:INTEGER;VAR RET_CODE:INTEGER);EXTERNAL;
 PROCEDURE SC_TSUSPEND(CMD_CODE:INTEGER;VAR RET_CODE:INTEGER);EXTERNAL;
```

Figure E-1. VPR tachograph task.

```
GLOBPROC ON
 PROCEDURE TACH_GRPH;
 BEGIN
   SPD_CH:=4;
   RPM_CH:=5;
   WHILE T_INDEX <= MAX_INDEX DO
     BEGIN
       LCL_AVG_SPD:=0;
       LCL_MAX_SPD:=-32767;
       LCL_MIN_SPD:=32767;
       LCL_AVG_RPM:=0;
       LCL_MAX_RPM:=-32767;
       LCL_MIN_RPM:=32767;
       FOR INDEX:=1 TO 300 DO
         BEGIN
           DATA:=DATA_BUF[SPD_CH];
           LCL_AVG_SPD:=LCL_AVG_SPD+DATA;
           IF DATA > LCL_MAX_SPD THEN LCL_MAX_SPD:=DATA;
           IF DATA < LCL_MIN_SPD THEN LCL_MIN_SPD:=DATA;
           DATA:=DATA_BUF[RPM_CH];
           LCL_AVG_RPM:=LCL_AVG_RPM+DATA;
           IF DATA > LCL_MAX_RPM THEN LCL_MAX_RPM:=DATA;
           IF DATA < LCL_MIN_RPM THEN LCL_MIN_RPM:=DATA;
           SC_TSUSPEND(0,RET_CODE);
         END;
       AVG_SPD[T_INDEX]:=LCL_AVG_SPD DIV 300;
       MAX_SPD[T_INDEX]:=LCL_MAX_SPD;
       MIN_SPD[T_INDEX]:=LCL_MIN_SPD;
       AVG_RPM[T_INDEX]:=LCL_AVG_RPM DIV 300;
       MAX_RPM[T_INDEX]:=LCL_MAX_RPM;
       MIN_RPM[T_INDEX]:=LCL_MIN_RPM;
       T_INDEX:=T_INDEX+1;
       SC_TSUSPEND(0,RET_CODE);
     END;
   SC_TDELETE(0,RET_CODE);
 END;
```

Figure E-1 (Cont'd).

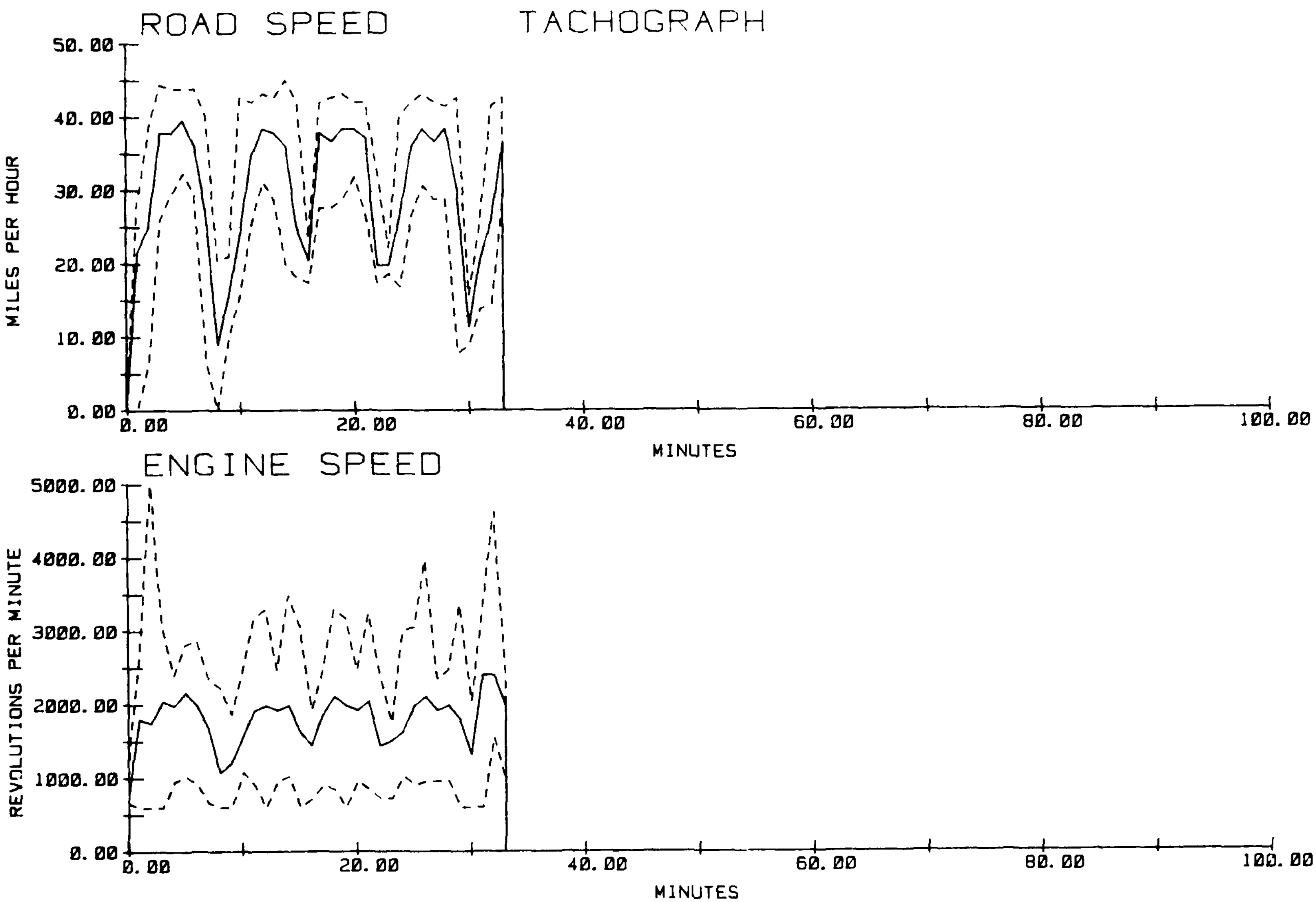
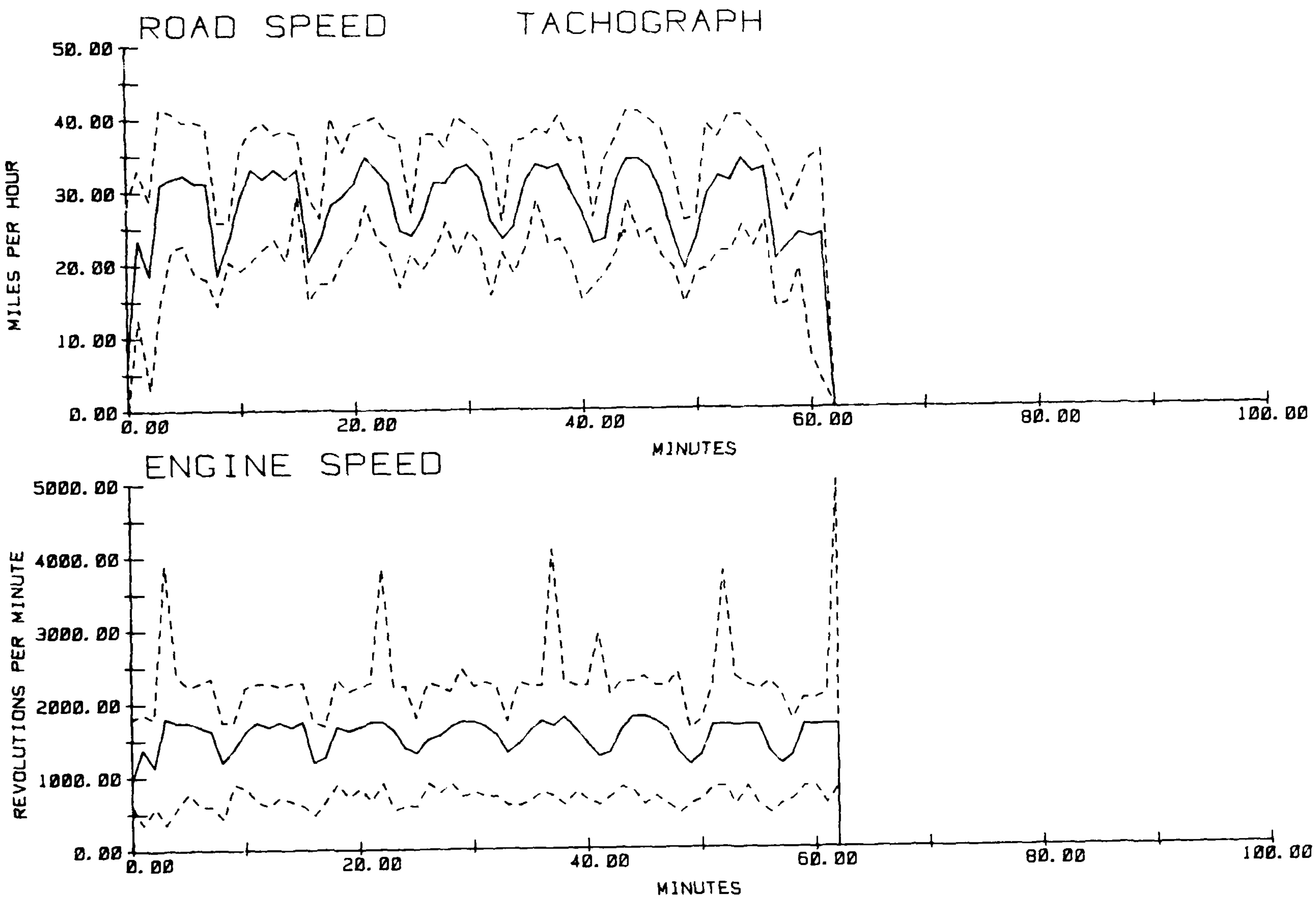

ROAD SPEED
TACHOGRAPH
50.00
40.00
30.00
20.00
10.00
0.00
MILES PER HOUR
0.00
20.00
40.00
60.00
80.00
100.00
MINUTES
ENGINE SPEED
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
REVOLUTIONS PER MINUTE
0.00
20.00
40.00
60.00
80.00
100.00
MINUTES

Figure E-2.


ROAD SPEED
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MINUTES
ENGINE SPEED
REVOLUTIONS PER MINUTE
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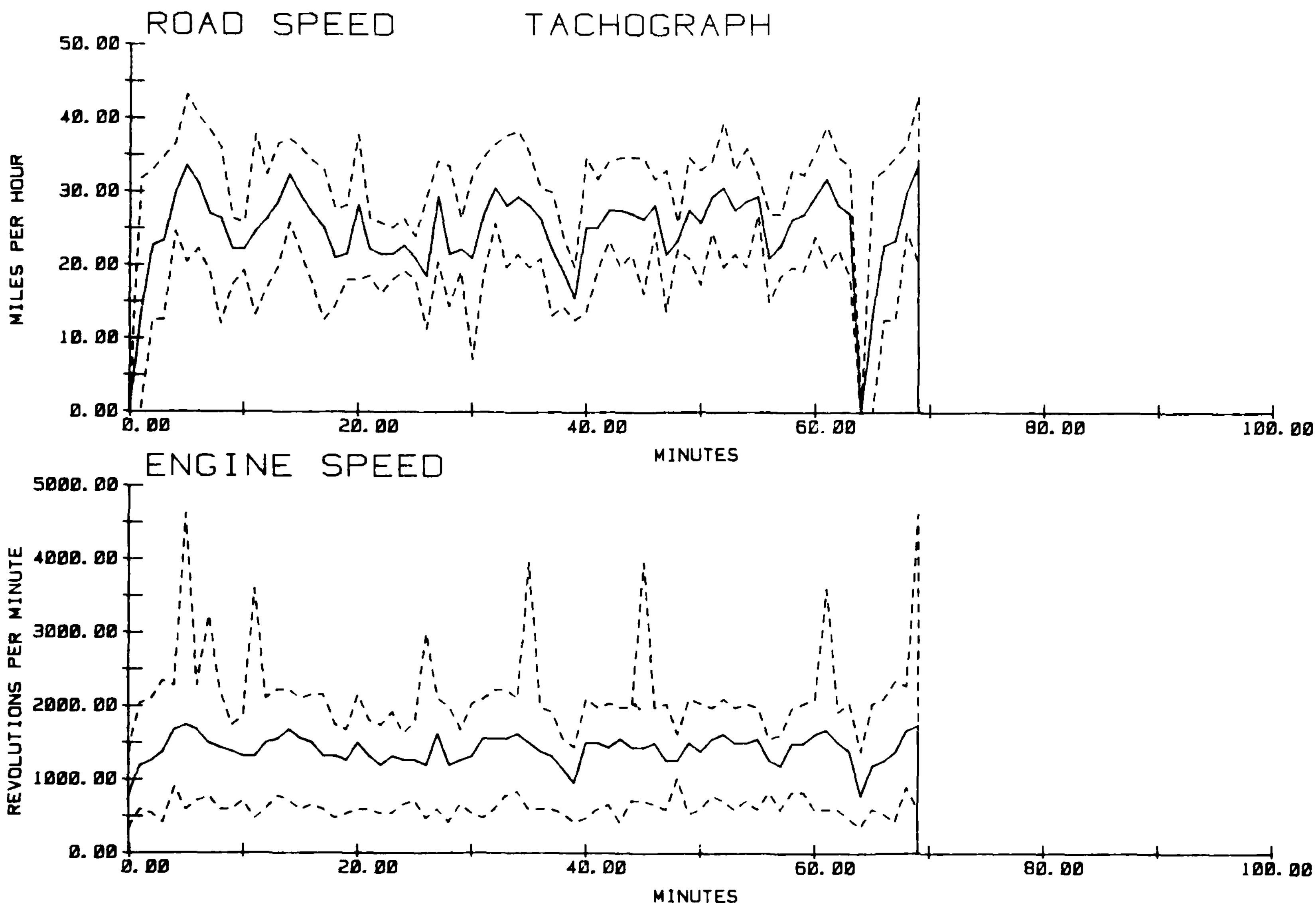
MINUTES

Figure E-3.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ENGINE SPEED
REVOLUTIONS PER MINUTE
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Figure E-4.

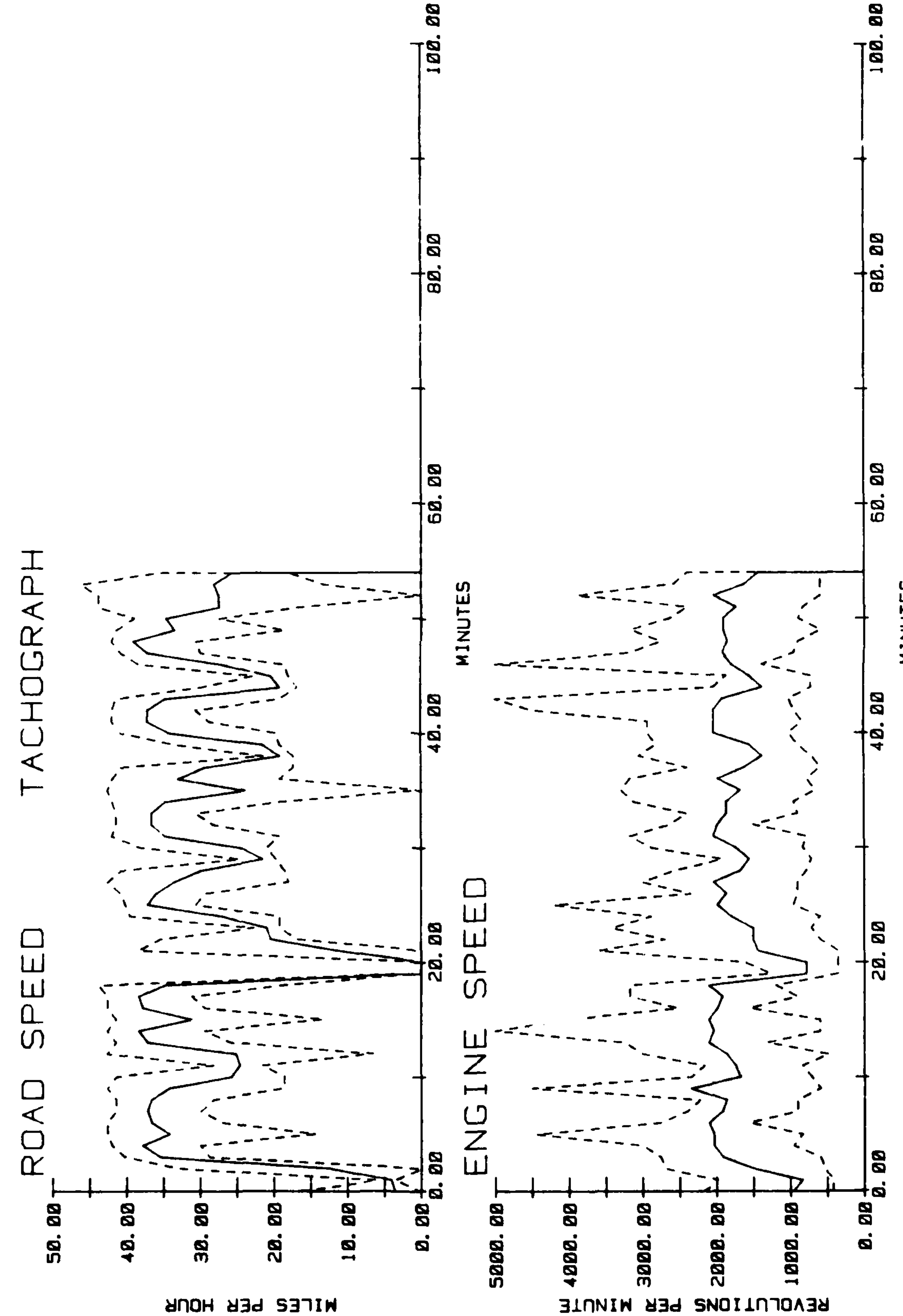
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Figure E-5.

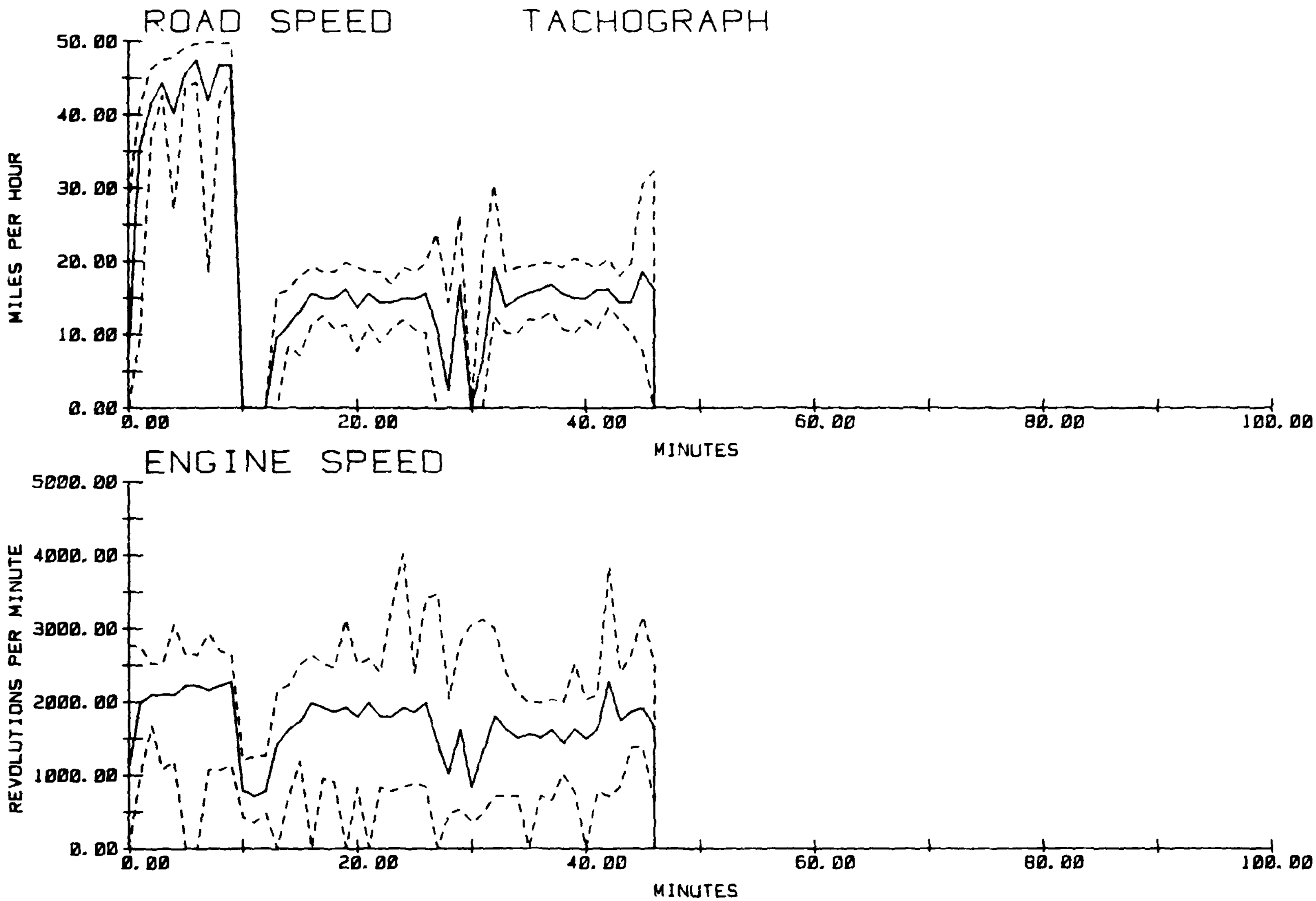
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Figure E-6.

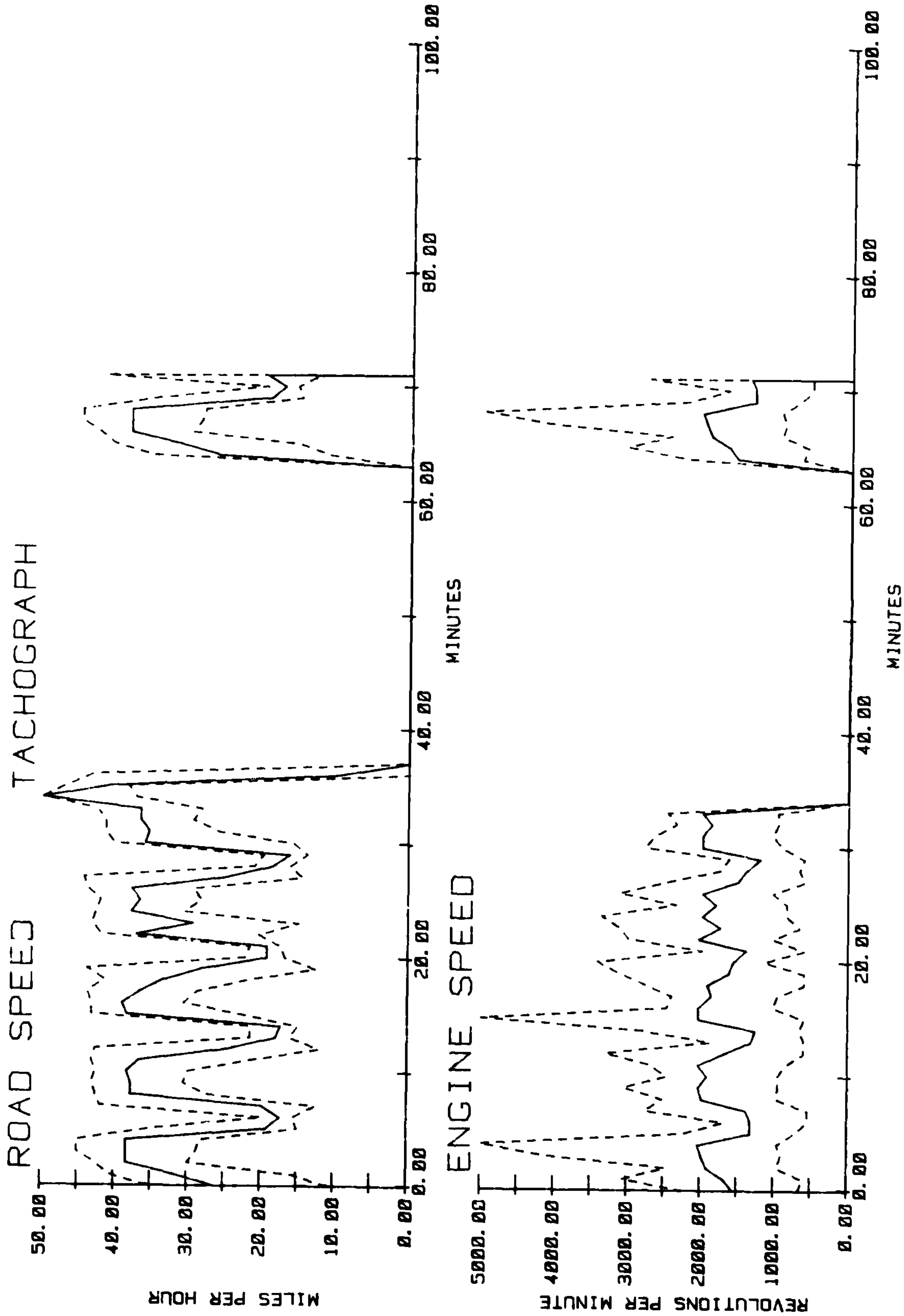

Figure E-7.

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APPENDIX F - RATIONALE FOR TEMPERATURE MEASUREMENTS

It is generally agreed within the testing community that it is desirable to measure engine load (in terms of delivered power or torque) during endurance testing. This parameter is very difficult to measure. In the environment encountered in endurance testing it is necessary that a surrogate parameter be used.

One possibility is exhaust gas temperature. Figure F-1 demonstrates the significance of this parameter. With a given adjustment and other fixed parameters (such as air filter conditions) the useful work output is:

$$W = \epsilon E$$

where

$$\epsilon \equiv \text{efficiency}$$

at the same time, the waste heat, is $H = (1-\epsilon)E$

$$= \frac{1-\epsilon}{\epsilon} W$$

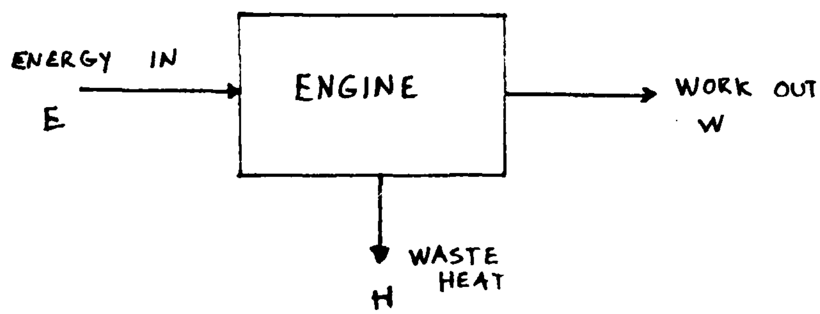

Figure F-1. Engine generation of waste heat.

Therefore (in this simplified discussion) the waste heat is directly proportional to the useful work output (of course, certain factors such as speed dependent efficiency distort this picture somewhat). The exhaust gas temperature directly reflects this waste heat. The major drawback to measuring this temperature is gaining access to the exhaust gas before it is subjected to various dispersive and cooling processes.

Figure F-2 depicts the relationship between transmission fluid temperature and required torque. In this case the waste heat is related to the torque output through the transmission efficiency.

$$H = (1 - \epsilon_T)\, T_{in}\, \omega_{in}$$

$$H = \frac{1 - \epsilon_T}{\epsilon_T}\, T_{out}\, \omega_{out}$$

Again, factors such as a speed or load dependent efficiency and cooling processes can distort this simplistic view.

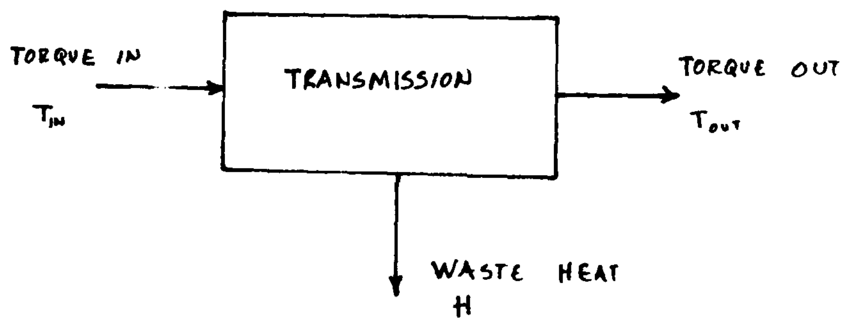

Figure F-2. Transmission generation of waste heat.

Reference 8 provides a discussion of the general performance characteristics of a hydrodynamic torque converter. Figure F-3, extracted from this reference, shows that converter torque ratio and efficiency are inversely related. Power lost in the converter due to inefficiency is absorbed by the oil, therefore the oil temperature will increase with the demand for torque (high torque ratio).

Because of unknown factors and processes no attempt should be made to map from exhaust or transmission temperature to output power or torque; however one or both could be used as an indication of engine loading.

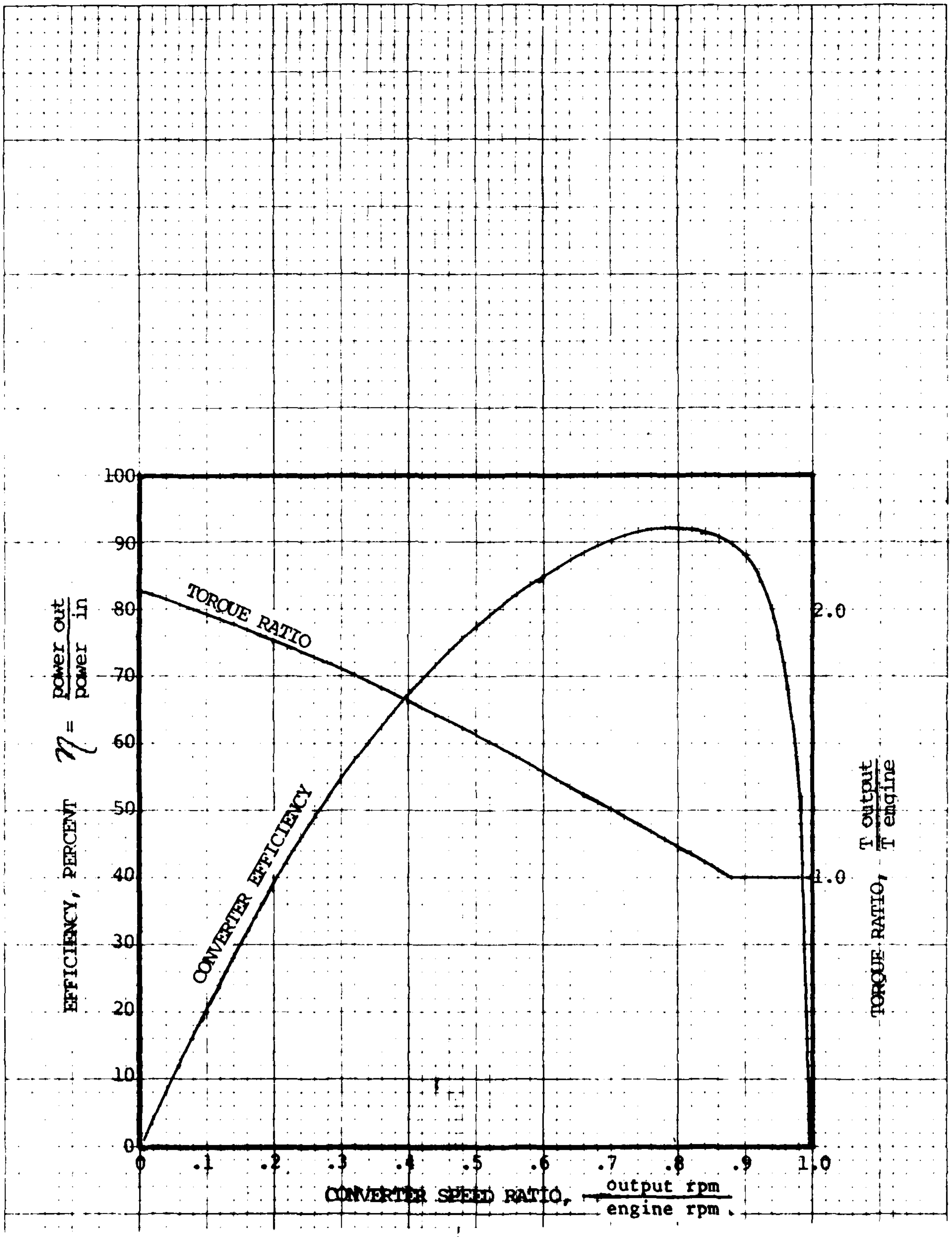

Figure F-3. Typical performance curves of a hydrodynamic torque converter.

APPENDIX G - BUMP RECORDER

G.1 System Description

The bump recorder which has been proposed for the HMMWV IPT is the B&K Type 2503 Bump Recorder. The following description and specifications (table G-1) are extracted from the manufacturer's literature.

The bump recorder is designed to measure and record the level and time of occurrence of mechanical shocks. Its primary application is in the field of goods transportation where rough handling methods often expose packages to higher shock levels than the transported object is designed to withstand. By establishing the severity of shocks occurring under transport it can be estimated whether damage is likely to have taken place, and if so, the time of occurrence will indicate where the responsibility lies.

The 2503 consists of a battery operated measuring instrument and strip recorder housed in a sturdy case and is intended to be transported with the goods to be monitored. The shock pick-up, an acceleration sensitive device called an accelerometer, is normally mounted on the transported object with a flexible cable connection to the measuring instrument, but it may also be mounted inside the instrument case itself.

In order to limit the data printout to shock events which have a severity approaching an estimated serious level, a Recording Threshold control is provided. The printout is only activated when this level, which can be preset between 1 and 100 g, is exceeded. The record strip then contains only significant data. The record consists of the time of occurrence, the maximum level attained, and the integral (with respect to time) of the acceleration pulse.

The input signal is conditioned in the input charge amplifier and then rectified to produce the signal which represents the acceleration-time history of the original shock. This combined signal feeds three circuits. The first is a Max Hold circuit which on command from the control logic retains the level of the largest acceleration signal which has occurred since it was last reset. Secondly, the signal is routed to the integrator, which is instructed to operate during the whole period during which the input signal exceeds a preset threshold level. The integrator produces a signal proportional to the bump velocity, and this is again fed to a Max Hold circuit. Thirdly, the acceleration signal is routed to a comparator which monitors the level. At the moment the level preset on the threshold selector is exceeded, the comparator informs the control logic, which starts the integrator and instructs the velocity and acceleration Max Hold circuits to retain the maximum level of the pulse which is building up. As the pulse dies away, the trigger level is crossed again, which is the event that prompts the control logic to initiate the readout sequence. The velocity and acceleration levels held in the Max Hold circuits are then released by the acceleration/ velocity selector and converted to digital values so that they can be held in a shift register (store). The data selector then routes the data to the printer; first the day, hour and minute of printout, then the stored maximum velocity and maximum acceleration levels are printed out.

During the 4 seconds taken for the data to be printed out, the instrument is still collecting information. As soon as the Max Hold circuits have passed on their information through the analog to digital converter to the digital store, they are free to collect new bumps. If the trigger level is again exceeded during the 4 second printout period the Max Hold circuits will hold the level of the most severe bump occurring during that time; these data are routed to the printer as soon as it is free from printing the previous bump event.

The thermal dot-printer prints out the data on a 6 mm wide strip of heat sensitive paper. Each character is built up from a 5 by 7 dot matrix. A full printout consisting of 28 characters and spaces takes 4 seconds. About 540 complete data events can be recorded on each roll of paper.

The crystal controlled clock has two functions; first, it acts as a reference for the control logic sequence, and secondly, it acts as relative timekeeper for the shock events recorded on the paper strip. The clock is reset at the beginning of each journey and from then on keeps time relative to the instant of resetting. Each bump level printout is preceeded by a printout of the relative time of occurrence in days, hours, and minutes. Furthermore, the clock is programmed to print out the time each hour or 24 hours, as selected, as an operational check on a large part of the system. If the instrument is switched off the clock is automatically reset.

The maximum velocity level is obtained by electronically integrating the acceleration pulse which has exceeded the preset threshold. The process of integration is in fact the measurement of the area under the acceleration-time curve. As the integrator only operates during the time which the input signal exceeds the threshold level, the acceleration-time history is not integratd during the beginning and end of the pulse. The area lost is dependent on the relative level of the trigger threshold and the actual signal maximum level. Where the threshold level is only marginally exceeded, the error should be compensated for by multiplying a correction factor which is extracted from the curve printed on the inside of the instrument case lid.

TABLE G-1. SPECIFICATIONS FOR THE TYPE 2503 BUMP RECORDER

Characteristics	Specifications
Measuring Ranges	
Pulse width	1 to 250 millisecond
Velocity	0.3 to 14 m/sec
Acceleration	1 to 500 g
Threshold Level	Switch selectable at 1,2,5,10,20,50,100 g's
Overall Accuracy	
With a half sinusodial pulse and input on 1 channel	
Acceleration	±10% ±1 least significant digit
Velocity	Not listed
Environmental Limits	
Vibration	13 m/sec 5 Hz to 27 Hz 0.9 mm pk-pk 27 Hz to 52 Hz 50 m/sec 52 Hz to 500 Hz
Maximum intermittant shock	1000 m/sec
Absolute maximum shock	1500 m/sec, pulse width <5 msec.
Maximum humidity	95%
Temperature range	-10 °C to +50 °C
Printer	
Paper	6-mm wide, heat sensitive
Capacity	540 printouts per roll
Speed	Complete printout of 28 characters requires 4 seconds
Clock	
Accuracy	±1 minute/week

2. System Utility

The simplest data reduction that can be used when dealing with a complicated time history is the condensation of that time history to a single number (app J, ref 8). Because of this simplicity single number analysis can appear to be quite attractive.

Consider the pulse shown in Figure G-1. The following single numbers analysis could be used in a description of this pulse:

a. The amplitude A_1.

b. The amplitude A_2.

c. The peak-to-peak amplitude $A_1 + A_2$.

d. The time duration t_1.

e. The time duration t_2.

f. The time duration $t_1 + t_2$.

g. The integral of the time history over the time interval t_1.

h. The integral of the time history over the time interval t_2.

i. The integral of the time history over the time interval $t_1 + t_2$.

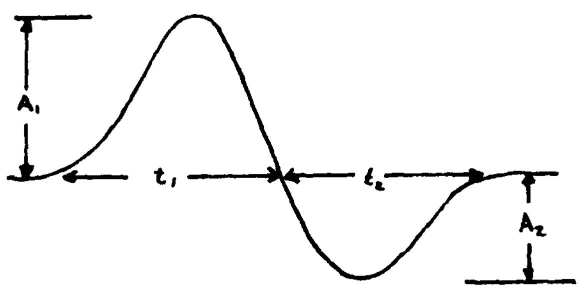

Figure G-1. Possible single number description of a pulse.

Whether any of these single number descriptions are sufficient to solve a given problem depends on the details of the specific problem. When the pulse shape is fixed and only the amplitude changes from instance to instance, clearly amplitude measurements alone can be used to compare the pulses. Unfortunately, without a prior knowledge that all pulses will be similar the usefulness of the amplitude and duration measurements must be questioned. The integral of an acceleration time history pulse over the duration of the pulse is a measure of the velocity change induced or energy imparted by the shock, and is thus a very important quantity. In the bump recorder, however, the signal is integrated only over that time interval that the acceleration exceeds a threshold value, as shown in Figure G-2. Furnished with the bump recorder is a correction table to account for that portion of the pulse not included in the integral, but this correction is based on the assumption that the acceleration pulse is a half-sinusoid. In addition, the negative portions of the signal are treated as separate input pulses which can generate misleading velocity changes.

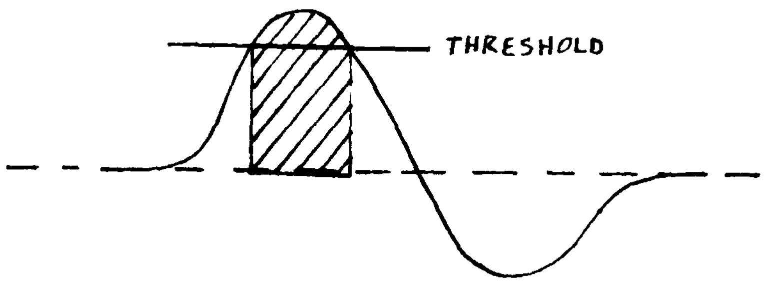

Figure G-2. Bump recorder integration.

Points which favor the use of the bump recorder in endurance testing are:

a. The system is simple in that it reduces the shock and vibration environment to a series of two number representatives.

b. The system is commercially available.

Points which do not favor the use of the bump recorder in endurance testing are:

a. The bump recorder concept oversimplifies the shock and vibration environment by making implicit assumptions regarding signal waveforms.

b. The bump recorder concept limits the examination of vehicle system inputs to the suspension.

c. The bump recorder output (print on paper) is not compat[illegible] with automatic data processing equipment, making it difficult to handle d[illegible] large numbers of vehicles during long duration tests.

d. No information is available (from manufacturer's literature or elsewhere) regarding the accuracy of velocity change measurements.

e. The bump recorder's upper temperature specification (122 °F) may preclude its use during some test situations (e.g. Yuma Proving Ground in midsummer).

APPENDIX H - DRIVE TRAIN LOAD PARAMETER TEST DATA

1. Data

Table H-1 provides a brief description of the HMMWV (VPR vehicle) used during this testing.

TABLE H-1. SUMMARY OF TEST VEHICLE SPECIFICATIONS

Vehicle Type: HMMWV (weapon carrier model).
Vehicle Identification: Engineering Model-14(EM=14).
Vehicle Gross Weight-(lb): 6580.
Engine: GMC, V-8 diesel, 6.2 L.
Transmission: Model THM 475/400 (hybrid).
Transfer: New process 218, full time 4-wheel drive.
Differential: Gleasman triple D.
Tires: 4 Ply, bias; size-(cm): 91.4 X 31.8 X 41.9.

Operating conditions for the resistance to tow testing are presented in Table H-2.

TABLE H-2. RESISTANCE TO TOW TEST CONDITIONS

Test Vehicle: HMMWV EM-14.
Test Course: Level pavement.
Vehicle Weight (lb): 6580.
Engine: Idle at 750 rpm.
Transmission: Neutral.
Transfer: High range, 1:1 ratio.
Differential Ratio: 2.56:1.
Hub Ratio: 1.92:1.
Tire Pressure-(psi): 22 front and rear.
Rolling Distance-(ft/rev): 8.73.

Resistance to tow test results are tabulated in Table H-3.

TABLE H-3. RESISTANCE TO TOW DATA

Vehicle Speed (mph)	Towing Resistance (lb)
5	134
10	153
15	178
20	202
25	216
30	211
35	236
40	247
45	259

Table H-4 is a compilation of full-load drawbar pull and temperature data measured during high range-first gear operation. The Delta Transmission Temperature is the temperature differential between hot transmission oil to the cooler and cooling air into the cooler.

TABLE H-4. FULL-LOAD DRAWBAR PULL AND TEMPERATURE DATA

Vehicle Speed (mph)	Engine Speed (rpm)	Drawbar Load (lb)	Delta Trans Temperature (°F)	Exhaust Temperature -°F				
				LC	RC	L 2	L 4	Ex OUT
Stall	1750	3380	216	746	771	684	736	403
4	1800	3000	169	678	710	622	662	368
6	1800	2780	187	879	897	814	844	552
8	1870	2640	188	927	921	834	845	375
11	1900	2200	168	923	967	863	887	461
13.7	2120	1900	125	874	900	820	853	341
17	2290	1540	131	930	947	885	902	427
20	2650	1500	130	929	932	888	884	451
26	3300	1520	122	896	924	743	872	447
31.8	4000	920	120	1021	1062	1027	994	563

LC = Outside surface of the left exhaust collector.
RC = Outside surface of the right exhaust collector.
L 2 = Outside surface of the left No. 2 exhaust header.
L 4 = Outside surface of the left No. 4 exhaust header.
EX OUT = Exhaust gas temperature at the outlet end of the exhaust pipe.

Table H-5 summarizes the Delta Transmission Temperature measured during high range - first gear road load testing.

TABLE H-5. ROAD LOAD TEST DATA

Vehicle Speed (mph)	Engine Speed (rpm)	Delta Trans Temp (°F)
5	800	49
10	1270	47
15	1880	59
20	2500	70
25	3100	67
30	3700	68
35	3900	74

2. Torque Calculations

Since transmission oil temperature was chosen as the load indicating parameter, temperature was related to the torque demand at the transmission output shaft. Appendix F contains the rationale for the connection between transmission fluid temperature and torque.

When the drive train is engaged from the ground to the transmission, drive train losses T_L can be approximated by measuring the resistance developed while towing the vehicle (resistance to tow). The major error introduced by this approach is that at higher road speeds the wind resistance on the test vehicle will be reduced by the towing dynamometer. T_D is the reserve torque remaining after overcoming the losses (T_L). At preselected road speeds throughout the speed range the steady state drawbar loads were measured and from these the equivalent drawbar torques (T_D) were computed.

To determine the low torque demand-temperature relationship a single gear of road load was run. During road load operation $T_D = 0$, therefore T_T T_L where T_T is the total output torque, under these conditions,

$$T_L = (F_r \times MA)/OR$$

$$MA = RD/_2 \quad = 8.73/_2 \quad = 1.39(ft)$$

$$OR = HR \times DR \times TR$$

where

F_r = Resistance to tow drawbar (lb)
MA = Moment arm (ft)
OR = Overall ratio
RD = Rolling distance (ft)
HR = Hub ratio (1.92:1)
DR = Differential ratio (2.56:1)
TR = Transfer ratio, high (1:1)

For first gear, high range operation

$$OR = 4.92:1$$

therefore

$$T_L = (F_r \times 1.39)/4.92 = F_r \times 0.283$$

Using a similar analysis;

$$T_D = (F_d \times MA)/OR = F_d \times 0.283$$

where

F_d is the drawbar force.

The transmission temperature - torque curve presented in Figure 3-20 utilized the torques computed by the method described above.

APPENDIX I - ABBREVIATIONS

ADAPT	Automated Data Acquisition and Processing Techniques
APG	Aberdeen Proving Ground
C	centigrade
CIM	CMOS Industrial Microcomputer
CMOS	Complimentary Metal Oxide - Silicon
CUCV	Commercial Utitlity Cargo Vehicle
ft-lb	foot-pound
g	acceleration of gravity
HMMWV	High Mobility Multi-Purpose Wheeled Vehicle
Hz	Hertz
IPT	Initial Production Test
mm	millimeter
mph	miles per hour
msec	millisecond
MTD	Materiel Testing Directorate
m/sec	meters per second
PCM	pulse code modulation
pk-pk	peak to peak
PROM	programmable read only memory
PSD	power spectral density
RAM	random access memory
RMS	root mean square
rpm	revolutions per minute
RTD	resistance temperature device
STE-ICE	Simplified Test Equipment - Internal Combustion Engine
VPR	Vehicle Performance Recorder
VRTX	Versatile Real Time Executive

APPENDIX J - REFERENCES

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6. Domanski, C., Development Test II (DT II) of the High Mobility Multi-Purpose Wheeled Vehicle (HMMWV), 1-1/4 Ton 4X4 Utility Cargo/Weapons Carrier, US Army Aberdeen Proving Ground, Engineering Test Branch, Field Engineering Section, Report No. 83-LR-7, February 1983.

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8. Elements of Automotive Engineering, Department of Ordnance, US Military Acadamy, West Point, NY, 1966.

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